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Report SRS-32

Ozark-Ouachita Highlands Assessment

Air Quality

REPORT

2

OF 5

Cover photo: Clear day in the Ozarks

Photo by A.C. Haralson, Arkansas Department of Parks and Recreation, Little Rock, AR.

Natural resource specialists and research scientists worked together to produce the five General Technical Reports that comprise the *Ozark-Ouachita Highlands Assessment*:

- Summary Report
- Air Quality
- Aquatic Conditions
- Social and Economic Conditions
- Terrestrial Vegetation and Wildlife

For information regarding how to obtain these Assessment documents, please contact: USDA Forest Service, P.O. Box 1270, Hot Springs, AR 71902 or telephone 501-321-5202.

To limit publication costs, few color maps and figures were used in the Assessment reports. For color versions of some of the Assessment figures and supplemental material, please see the Assessment's home page on the Internet at <<http://www.fs.fed.us/oonf/ooaha/welcome.htm>>. The Assessment reports will be online for about 2 years after the date on this publication; then they will be archived.

Please note: When "authors" are agency or business names, most are abbreviated to save space in the citations of the body of the report. The "References" at the end of the report contain both the full name and abbreviations. Because abbreviations sometimes are not in the same alphabetical order as the references, for clarifications of abbreviations, consult the "Glossary of Abbreviations and Acronyms."

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Ozark-Ouachita Highlands Assessment:

Air Quality

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Preface

Change is evident across the Ozark and Ouachita Highlands. Whether paying attention to State and regional news, studying statistical patterns and trends, or driving through the Highlands, one cannot escape signs that growth may be putting strains on the area's natural resources and human communities. How people regard these changes varies widely, however, as does access to reliable information that might help them assess the significance of what is happening in the Highlands. The Assessment reports provide windows to a wealth of such information.

The *Air Quality* report is one of five that document the results of the Ozark-Ouachita Highlands Assessment. Federal and State natural resource agency employees and university and other cooperators worked together to produce the four technical reports that examine air quality; aquatic conditions; social and economic conditions; and terrestrial vegetation and wildlife. Dozens of experts in various fields provided technical reviews. Other citizens were involved in working meetings and supplied valuable ideas and information. The *Summary Report* provides an overview of the key findings presented in the four technical reports. Data sources, methods of analysis, findings, discussion of implications, and links to dozens of additional sources of information are included in the more detailed technical reports.

The USDA Forest Service initiated the Assessment and worked with other agencies to develop a synthesis of the best information available on conditions and trends in the Ozark-Ouachita Highlands. Assessment reports emphasize those conditions and trends most likely to have some bearing on the future management of the region's three national forests—the Mark Twain, Ouachita, and Ozark-St. Francis. People who are interested in the future of the region's other public lands and waters or of this remarkable region as a whole should also find the reports valuable.

No specific statutory requirement led to the Assessment. However, data and findings assembled in the reports will provide some of the information relevant for an evaluation of possible changes in the land and resource management plans of the Highland's three national forests. The National Forest Management Act directs the Forest Service to revise such management plans every 10 to 15 years, which means that the national forests of Arkansas, Missouri, and Oklahoma are slated to publish revised plans in the year 2001. Due to restrictions in the 1998 appropriations bill that provides funding for the Forest Service, it is uncertain when these revisions can begin.

The charter for the Ozark-Ouachita Highlands Assessment established a team structure and listed tentative questions that the teams would address. Assembled in mid-1996, the Terrestrial, Aquatic and Atmospheric, and Human Dimensions (Social-Economic) Teams soon refined and condensed these questions and then gathered and evaluated vast quantities of information. They drafted their key findings in late 1997 and refined them several times through mid-1999. In addition to offering relevant data and key findings in the reports, the authors discuss some of the possible implications of their findings for future public land management in the Highlands and for related research. The Assessment reports, however, stop well short of making decisions concerning management of any lands in the Highlands or about future research. In no way do the reports represent management plans. Instead, the findings and conclusions offered in the Assessment reports are intended to stimulate discussion and further study.

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Executive Summary

This Assessment of the Ozark-Ouachita Highlands area began in May of 1996 and was completed in May of 1998. It was designed as an interagency effort led by the USDA Forest Service to collect and analyze ecological, social, and economic data concerning the Highlands of Arkansas, Missouri, and Oklahoma. The information compiled will facilitate an ecosystem approach to management of the natural resources on public lands within the Ozark Highlands, the Boston Mountains, the Arkansas River Valley, and the Ouachita Mountains. The Atmospheric Team studied air quality conditions in these and surrounding areas.

The Atmospheric Team, with input from scientists, forest planners, and concerned citizens, identified five questions that needed to be addressed in order to understand air quality conditions and trends in the Ozark-Ouachita Highlands. Following is a summary of the team's findings.

Chapter 1: Major Air Pollutants

What are the major emissions characteristics in the Ozark-Ouachita Highlands Assessment area, and what areas receive the greatest exposure to pollutants?

- The major types of air-pollution emissions with the potential to impact the natural resources of the Ozark-Ouachita Highlands are particulate matter, nitrogen oxides, volatile organic compounds, and sulfur dioxide.
- Emissions of particulate matter are greatest along the northern and western boundaries of the Assessment area, where they are usually generated by fugitive dust sources (e.g., sources of uncontrolled dust emissions such as dirt roads or agriculture fields). Emissions in the future are expected to remain constant unless wildland fires or prescribed fires increase beyond current levels.
- Motor vehicles and electrical utilities are the usual sources of nitrogen oxides nationally; however, in the Assessment area, fuel combustion at industrial sources is the major source of these emissions. Current measures taken by the U.S. Environmental Protection Agency (EPA) are likely to reduce emissions of nitrogen oxides from electrical utilities and possibly other sources.

- Nationally and in the Ozark-Ouachita Highlands, motor vehicles are the main source of volatile organic compounds caused by human activities. Available data were insufficient to enable the Atmospheric Team to project how volatile organic compounds will change in the future.
- Fuel combustion from electrical utilities is the greatest source of sulfur dioxide in the Highlands area; the Atmospheric Team expects the amount of emissions to decrease in the future due to the enactment of and full compliance with the Clean Air Act amendments of 1990.

Chapter 2: Particulate Matter (PM₁₀) in the Air

What is the status of particulate matter in the Ozark-Ouachita Highlands?

- Particulate matter (PM₁₀) concentrations show a definite seasonal trend over the Assessment area. The highest concentrations between 1991 and 1995 were during the summer months, with an average period concentration of 33.05 milligrams per cubic meter ($\mu\text{g m}^{-3}$); the average winter concentration was 19.84 $\mu\text{g m}^{-3}$.
- Rural areas have lower PM₁₀ concentrations than urban areas.
- There is a spatial distribution of PM₁₀ across the Assessment area, with the lowest annual average PM₁₀ concentrations occurring in western Arkansas.
- The Assessment area is well within the National Ambient Air Quality Standards (NAAQS) for PM₁₀. Implementation of the new PM_{2.5} regulations may create a challenge to prescribed burning programs of farmers and land management agencies such as the USDA Forest Service.

Chapter 3: Visibility

How good is visibility in the Assessment area; how does air pollution affect visibility?

- A definite seasonal pattern exists. The best visibility occurs during the fall, and the worst visibility occurs during the summer. (Summer is also the time of highest PM_{2.5} concentrations.)

- The Upper Buffalo Wilderness on the Ozark-St. Francis National Forests has the best visibility of the three Class I wilderness areas on national forests within the Assessment area.
- Visibility impairment in the form of regional haze exists within the Assessment area, but the team found that there is insufficient data to identify trends.
- Sulfates are the primary aerosols responsible for visibility impairment within the Assessment area.
- Compliance with the Clean Air Act amendments of 1990 should reduce sulfates and improve visibility.

Chapter 4: Ground-Level Ozone

What impact does ground-level ozone have on forests?

- Using available ozone monitoring data, it appears that ground-level ozone had a minimal impact on forest tree growth between 1990 and 1995.
- There are few ozone monitors within the Assessment area. Consequently, there could be localized areas where growth losses occurred in trees that are highly sensitive to ozone.
- Future ozone exposure may be less as Federal, State, and local air pollution control agencies implement strategies to reduce pollution, especially nitrogen oxide.

Chapter 5: Acid Deposition

To what extent are resources in the Highlands being affected by acid deposition?

- Atmospheric wet acid loadings are less than the loadings observed in the Southern Appalachian region. Nitrate and sulfate loadings are expected to decrease in the future.
- Most surface waters within the Assessment area do not appear to be adversely impacted by the previous and present rate of acid deposition.
- The low acid neutralizing capacity headwater areas of the Ouachita Mountains make them most at risk while the limestone areas of the Ozark Highlands are least at risk.

Implications and Opportunities

Each chapter concludes with a section on the implications and opportunities that the key findings present for management and research in the Assessment area. Following is a brief summary of implications and opportunities for each subject.

Emissions

To discuss air quality within the Assessment area, the Atmospheric Team needed to understand where pollution releases are the greatest and what types of sources are emitting specific pollutants. The team compiled county-level data that can be used by land managers and others to see how a proposed action may influence emissions. Emissions estimates are critical for such determinations.

Particulate Matter (PM₁₀)

Approximately 70 percent of the particulate matter produced by wildland fuels is within the PM_{2.5} size class (diameter of 2.5 microns or smaller). Proposed regulations call for the 24-hour standard to be less than 65 µg m⁻³ and the annual average to be less than 15 µg m⁻³. The 1992 to 1995 annual average concentration of such fine mass particles was between 9 and 11 µg m⁻³ over the more rural parts of the Assessment area based on interpolated IMPROVE network data. These concentrations represent 60 to 73 percent of the proposed standard annual average of 15 µg m⁻³ and 18 to 22 percent of the current annual standard of 50 µg m⁻³. Thus, even with the implementation of the new PM_{2.5} standards, the more rural sections of the Assessment area should still be in compliance if current PM_{2.5} concentration averages continue to characterize the region.

According to Forest Service records, most prescribed burning occurs during March in the Assessment area. Average PM₁₀ concentrations in the Assessment area during the month of March (1991 to 1995) ranged from minimums of 10 to 20 µg m⁻³ to maximums of 30 to 40 µg m⁻³, with a mean of 22.7 µg m⁻³. If prescribed fire becomes a more prominent land management tool in the Assessment area during the normal prescribed fire season, total PM₁₀ and PM_{2.5} emissions and concentrations in the atmosphere will likely increase during the springtime.

Visibility

Title IV (Acid Deposition Control) of the Clean Air Act amendments of 1990 specifies that sulfur dioxide emissions be reduced by 10 million tons and nitrogen oxide emissions by 2 million tons from 1980 emission levels. When these reductions are fully implemented by the year 2000, visibility should be improved. Sulfates are the major factor in visibility reduction, especially during the summer when visibility is poorest. Newly proposed PM_{2.5} and ozone regulations, while targeted to improve human health, should have the added benefit of improving visibility through anticipated reductions in atmospheric sulfate concentrations.

Ground-Level Ozone

Ozone exposures in the study area result from the chemical reaction of nitrogen oxides and volatile organic compounds. The volatile organic compounds are known to be so abundant that it appears nitrogen oxides may be the limiting factor in ozone formation. Implementation of and compliance with the Clean Air Act Amendments of 1990 should reduce nitrogen oxide emissions nationally by 2 million tons and may reduce ozone exposures further within the Assessment area. Other strategies that reduce nitrogen oxides may also result in lower ozone exposures for the Ozark-Ouachita Highlands area. Recently, the EPA notified State and local air pollution control agencies in 22 Eastern States that further reductions in nitrogen oxides are needed for some urban areas to satisfy the NAAQS for ground-level ozone. Included were Illinois,

Kentucky, Missouri, and Tennessee, where the needed reduction of nitrogen oxides is between 35 and 43 percent. Implementation of nitrogen oxide reductions of this magnitude likely will reduce the amount of ground-level ozone in the Assessment area.

Acid Deposition

Acid deposition can pose a threat to forest ecosystems—especially on poorly buffered, higher elevation watersheds. Acid deposition patterns in the Assessment area are affected by emissions of sulfur dioxide and nitrogen oxides and by the patterns of precipitation over the region. Future reductions in the emissions of sulfur dioxide and nitrogen oxides should lead to reduced atmospheric sulfate and nitrate concentrations, thereby reducing the potential for acid deposition episodes. However, future changes in precipitation patterns as a result of changes in regional climate may also influence the amount of acid deposition over the Assessment area.

Comprehensive assessments of future acid deposition patterns over the Assessment area will require the use of coupled high-resolution models that take into account complex atmospheric processes, cloud formation and precipitation occurrence, surface-atmosphere interactions as they relate to the hydrologic cycle, and the chemical reactions that control the formation of sulfuric and nitric acid in the atmosphere. Information from these models should aid natural resource managers in the development of management strategies for watersheds in the Assessment area that are sensitive to acid rain episodes.

Chapter 1: Major Air Pollutants

Question 1: What are the major emissions characteristics in the Ozark-Ouachita Highlands Assessment area, and what areas receive the greatest exposure to pollutants?

Air Quality in the Assessment Area

The term “air pollution” calls up images of dark fumes billowing from tailpipes, black smoke from factory chimney stacks, or smog hanging over a city. Americans depend on the combustion of fossil fuels for transportation, electricity, industrial processes, and heating homes and businesses. This combustion of fossil fuels not only generates energy, it also creates toxic gases and particulates. These pollutants can be transformed in the atmosphere and transported throughout the area of origin and beyond. People and resources in the Ozark-Ouachita Highlands Assessment area (fig. 1.1) cannot escape air pollution and its effects.

Rarely can air pollution impacts be traced back to a single source. Moreover, pollutants are generated from both within and outside of the Assessment area—even from hundreds of miles away. Air pollution is produced by both human and natural activities and has three major sources: (1) stationary or point sources such as power-generating plants, service stations and industrial facilities; (2) area sources such as dust from roads and smoke from fires; and (3) mobile sources such as automobiles, trucks, and aircraft. The primary pollutants (such as sulfur dioxide or nitrogen oxides) emitted directly from these sources are transformed in the atmosphere into secondary pollutants such as sulfate or nitrates. In this report, the secondary pollutants discussed are those that most likely affect the forest environment.

The information presented in the following sections is for a broad-scale assessment that focuses on air quality issues concerning potential impacts to forest ecosystems. The information and data presented should be used

cautiously and may not be appropriate for local planning; that is, a statement that in general holds true for the whole Ozark-Ouachita Highlands may not hold true for a specific site in the Assessment area.

Primary Pollutants

Natural events such as dust storms, lightning-caused wildfires, and volcanoes release pollutants into the atmosphere as do human activities (also called anthropogenic sources) such as agriculture, industry, transportation, and prescribed fires.

In their analysis, the Atmospheric Team identified four primary pollutants released from human activities that eventually affect the Assessment area: particulate matter (10 microns and smaller, called PM₁₀), nitrogen oxides, volatile organic compounds, and sulfur dioxide. These pollutants represent some of the six “Criteria Pollutants” recognized by the U.S. Environmental Protection Agency (EPA) (U.S. EPA 1995). The team selected these primary pollutants because secondary pollutants formed from them are suspected of causing visibility reductions and impacts to vegetation and aquatic ecosystems. Information presented on these primary pollutants includes the location and intensity of emissions and likely future trends in emissions.

Regional climate change resulting from emissions of carbon dioxide and other greenhouse gases is not discussed in this report. Although the team recognized that resources in the Ozark-Ouachita Highlands could be susceptible to climatic change, uncertainty concerning the nature of regional climatic changes and the global aspects of the phenomenon led the team to conclude that a comprehensive analysis of this issue was beyond the scope of this Assessment. However, an overview of the baseline climatic characteristics in the Assessment area can be found in the “Climate” section of Chapter 1 of the *Ozark-Ouachita Highlands Assessment: Aquatic Conditions* (USDA FS 1999).

Key Findings

1. The major types of air-pollution emissions with the potential to impact the natural resources of the Ozark-Ouachita Highlands are particulate matter, nitrogen oxides, volatile organic compounds, and sulfur dioxide.
2. Emissions of particulate matter are greatest along the northern and western boundaries of the Assessment area, where they are usually generated by fugitive dust sources (e.g., sources of uncontrolled dust emissions such as dirt roads or agriculture fields). Emissions in the future are expected to remain constant unless wildland or prescribed fires increase beyond the current normal occurrences.
3. Nationally, motor vehicles and electrical utilities are the usual sources of nitrogen oxides; however, in the Assessment area, fuel combustion at industrial sources is the major source of these emissions. Current measures taken by the U.S. Environmental Protection Agency are likely to reduce emissions of nitrogen oxides from electrical utilities and possibly other sources.
4. Nationally and in the Ozark-Ouachita Highlands, motor vehicles are the main source of volatile organic compounds caused by human activities. Available data were insufficient to enable the Atmospheric Team to project how volatile organic compounds will change in the future.
5. Fuel combustion from electrical utilities is the greatest source of sulfur dioxide in the Highlands area; the Atmospheric Team expects the amount of emissions to decrease in the future due to the enactment of and full compliance with the Clean Air Act Amendments of 1990.

Data Sources and Methods of Analysis

States included in this analysis—Arkansas, Illinois, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Nebraska, Oklahoma, Tennessee, and Texas—are located within 120 miles of the Ozark-Ouachita Highlands Assessment boundary. Table 1.1 lists the main categories of emissions used in the analysis for this Assessment (Miller 1997).

The Atmospheric Team obtained data from the EPA for county-level estimates (tons/year) of emissions from

point and area sources for the 11 States. The team used the adjusted data from the EPA’s 1985 National Acid Precipitation Assessment Program (NAPAP) inventory, using economic activity data to estimate the emissions for 1994. The NAPAP inventory is organized by area and point source emission categories (Placet and others 1991).

The EPA also provided 1995 data on emissions of natural sources of nitrogen oxides and volatile organic compounds for each county within the area (U.S. EPA 1996). A simple rating system developed by the EPA (1996) was used to classify each county by the amount of natural or anthropogenic emissions recorded there. The team categorized each county by dividing the emissions estimate for a pollutant by the area of the county, resulting in “tons/square mile” (tons/mi²). They condensed the five category system (table 1.2) used by the EPA (1996) into three categories: (1) low or below average, (2) average or above average, and (3) high. These categories allow comparisons of the emissions from a particular county with emissions from other areas in the United States. For example, a county with high emissions of nitrogen oxides in the Assessment area would have more

Table 1.1—Main categories of area, mobile, and point source emissions in the Assessment area

Category number	Main category name
1	Fuel combustion, electrical utility
2	Fuel combustion, industrial
3	Fuel combustion, other
4	Chemical and allied product manufacturing
5	Metals processing
6	Petroleum and related industries
7	Other industrial processes
8	Solvent utilization
9	Residential wood and other
10	Waste disposal and recycling
11	Highway vehicles
12	Off-highway vehicles
13	Natural sources
14	Miscellaneous
15	Off-highway, other
16	Agriculture and forestry
17	Fugitive dust

Source: Miller (1997).

Table 1.2—Emissions categories described by the range of pollutants (tons per square mile) resulting from natural sources and human activities

Category	Natural		Human activity			
	NO _x	VOC	PM ₁₀	NO _x	VOC	SO ₂
----- Tons per square mile -----						
Low	0 – 0.20	0 – 2.0	0 – 6.9	0 – 1.13	0 – 1.21	0 – 0.07
Below average	0.21 – 0.30	2.1 – 6.0	7.0 – 10.3	1.14 – 2.40	1.22 – 2.61	0.08 – 0.20
Average	0.31 – 0.60	6.1 – 15.0	10.4 – 14.2	2.41 – 4.60	2.62 – 4.76	0.21 – 0.70
Above average	0.61 – 1.0	15.1 – 25.0	14.3 – 19.7	4.61 – 11.40	4.77 – 11.53	0.71 – 4.80
High	> 1.0	> 25.0	> 19.7	> 11.40	> 11.53	> 4.80

NO_x = nitrogen oxides; VOC = volatile organic compounds; PM₁₀ = particulate matter 10 microns or smaller; SO₂ = sulfur dioxide.

Source: U.S. EPA (1996).

emissions per square mile than most counties in the United States.

It is difficult to define a specific boundary area for “contributing” sources because the atmospheric processes that control pollutant formation and transport vary by pollutant and as a function of weather conditions. Sources within the designated 120-mi radius and more distant sources could contribute to pollutant levels. Atmospheric transport and dispersion models are traditionally used to simulate pollution exposures across the landscape or to map the potential downwind impact of a pollution source. The most accepted regional models are very expensive to use and were beyond the financial resources of this Assessment. Instead, a simplified approach called statistical modeling was used for the analysis. As shown in figure 1.2, the Atmospheric Team located 28 receptors (spatial locations) over the Assessment area, using a 60-mi by 60-mi spacing. The team selected a 120-mi radius to illustrate which sections of the Ozark-Ouachita Highlands are likely to receive the greatest pollution exposure. Only anthropogenic emissions within 120 mi of the receptors were used in the simple modeling exercise.

The statistical model used for this Assessment is called the Pollution Exposure Index (PEI) (Miller 1997). The model has been developed using ArcView® software as an interface to perform the calculations. The team used emissions from up to 405 counties in the analysis. If emissions from a county were less than 40 tons/year, the team did not use them in the PEI model. Separate calculations were performed for PM₁₀, nitrogen oxides, sulfur

dioxide, and volatile organic compounds. The model used the following equation:

$$PEI_{ip} = \sum_{j=1}^N [(F_{ij} * T_{ij}) * Q_{jp} / D_{ij}]$$

and calculated a value for each of the 28 receptors. (See the sidebar for a complete explanation of the equation used.)



Figure 1.2—Location of receptors used for statistical modeling of pollution exposure within and near the Assessment area.

The Atmospheric Team used the unpublished PEI model described by Miller (1997), which is as follows:

$$PEI_{ip} = \sum_{j=1}^N [(F_{ij} * T_{ij}) * Q_{jp} / D_{ij}]$$

where

PEI_{ip} = total index value for each receptor and pollutant of interest.

i = receptors.

p = pollutant of interest.

N = total number of sources.

j = source (i.e., the emissions from a county).

F_{ij} = annual wind direction percent frequency (using a 22.5 degree “window”), using the nearest surface wind station between the receptor and source.

T_{ij} = the calculated terrain factor between the receptor and the source (i.e., the county center).

Q_{jp} = pollutant emission rate (tons per year) for a particular pollutant.

D_{ij} = distance (kilometers) between the receptor and the source. Values less than or equal to 0.06 miles (0.1 km) were set to 0.06 miles (0.1 km).

The terrain factor (T_{ij}) is an adjustment made if there are mountains between the receptor and source. The calculation uses the following two equations:

$$E_c = \max (E_r, E_s, E_m)$$

$$T_{ij} = M_h / M_h + (E_c - E_s)$$

where

E_c = largest value for E_r, E_s, or E_m.

E_r = maximum receptor elevation (feet).

E_s = maximum source (i.e., county center) elevation (feet).

E_m = highest elevation (feet) along a line drawn between the source and the receptor.

M_h = mixing height (average annual value of 2,689 feet was used).

The team then used the values at the receptors to estimate the PEI values between the receptors. Spatial Analyst® (an ArcView® extension) was used to perform the estimates (also called interpolations). The team used a spline technique for the interpolations to a 6-mi by 6-mi grid. The nearest 12 points to each grid were used for the spline interpolation. The results for the PEI model are given in tons per year per kilometer, which lacks meaning except as an index. Those areas with the highest values are believed to have the highest risk of impact from a particular pollutant. The results from the PEI model should be used cautiously and in conjunction with available ambient monitoring data.

Patterns and Trends

Particulate Matter

Particulate matter in the atmosphere includes wind-blown soil, soot, smoke, and liquid droplets. It also includes fine particles of sulfates, nitrates, and organic compounds that are 2.5 microns or smaller in size (PM_{2.5}). Particles are emitted into the air by sources such as factories, power plants, construction activities, automobiles, fires, and agricultural activities. Relative to the United States as a whole, many counties on the northern and western boundaries of the Assessment area have high emissions of PM₁₀ (fig. 1.3). Within the

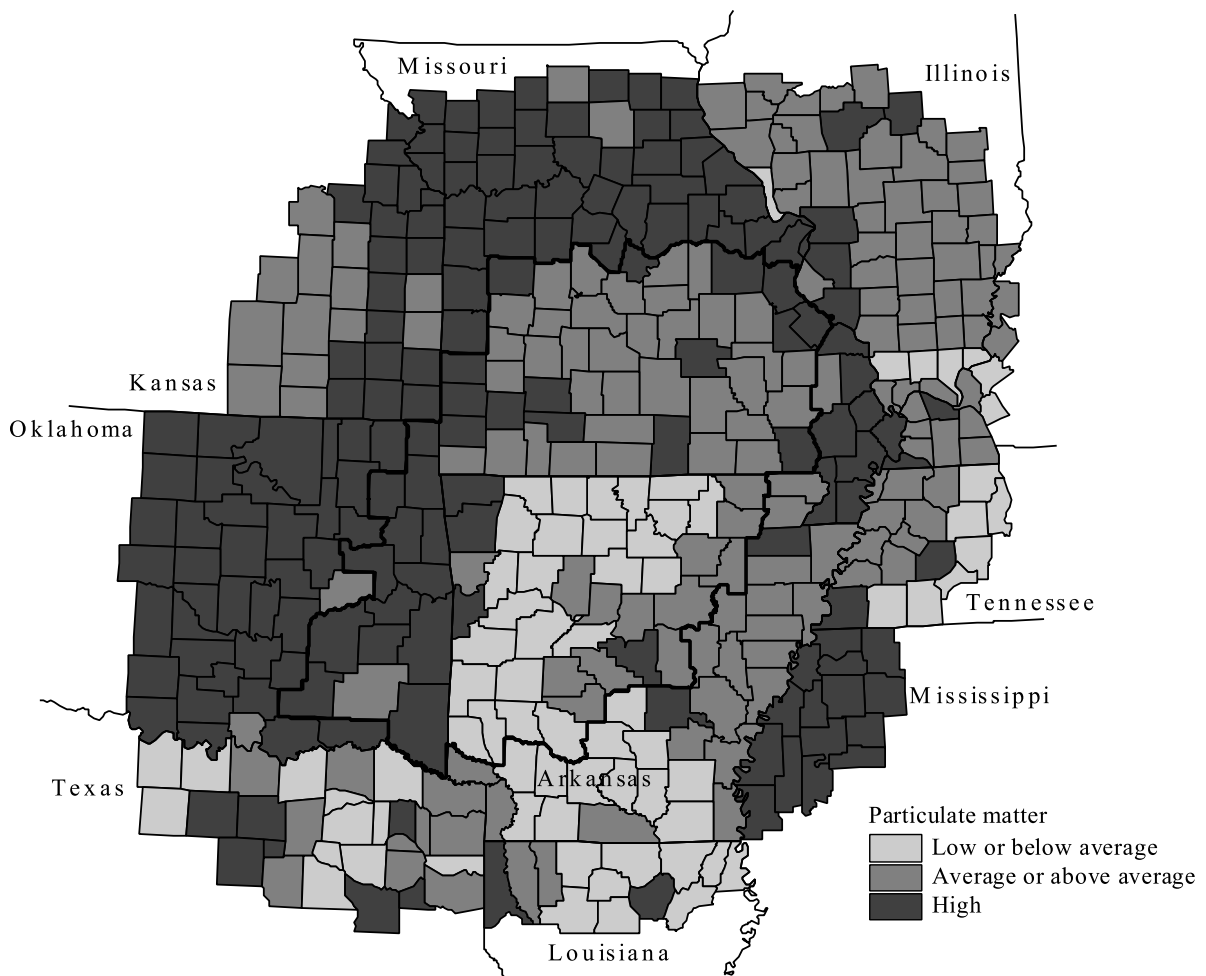


Figure 1.3—Estimates of emissions of particulate matter 10 microns or smaller (PM_{10}) in Assessment area and surrounding counties in 1994 (U.S. EPA 1995).

Arkansas portion of the Assessment area, most of the counties have low or below average emissions compared to the rest of the United States (U.S. EPA 1996). Fugitive dust is the greatest emission source of PM_{10} (71 percent) from within and outside the Assessment area (fig. 1.4). The second largest source of emissions is from agriculture and forestry practices (18 percent). Emissions of PM_{10} from fuel combustion and other industries (stationary sources) comprise a small portion (3 percent) of the total emissions within 120 mi of the receptors (fig. 1.4).

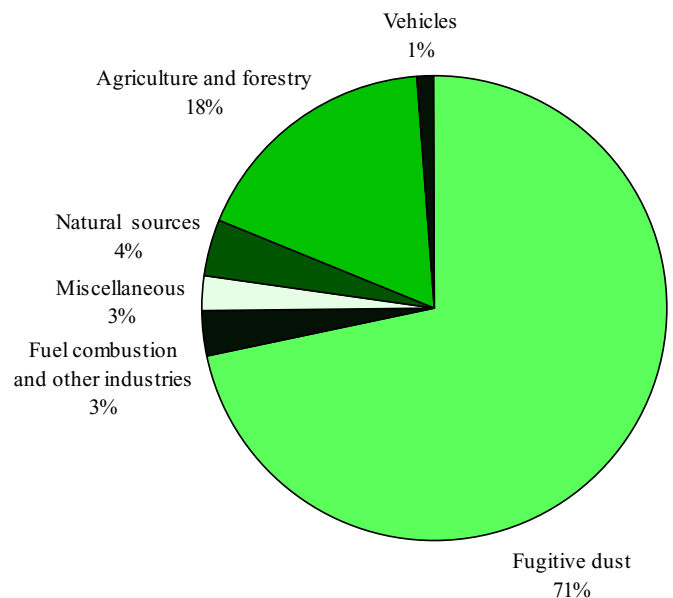


Figure 1.4—Particulate matter emissions 10 microns or smaller (PM_{10}) by source categories in 1994 (U.S. EPA 1995).

Nitrogen Oxides

More than 95 percent of nitrogen oxide emissions is in the form of nitric oxide. In the presence of volatile organic compounds and sunlight, this gas is rapidly converted in the atmosphere to nitrogen dioxide, which can subsequently be altered by sunlight to produce ozone. Available evidence suggests that nitrogen oxides are a controlling factor in the formation of ground-level ozone in rural areas of the Southern United States (Chameides and Cowling 1995). When trapped in sufficient quantities, nitrogen dioxide can be seen as a brownish haze. Secondary pollutants formed from nitrogen oxides also reduce visibility and contribute to acid deposition. The largest contributors of nitrogen oxides within 120 mi of the receptors (fig. 1.5) are fuel combustion from industrial sources (28 percent), motorized vehicles (22 percent), and electrical utilities (20 percent). Nationally, greater portions of total nitrogen oxide emissions come from

motorized vehicles (45 percent) and electrical utilities (33 percent). On the other hand, national nitrogen oxide emissions from industrial fuel combustion comprise a smaller portion (14 percent) of the total than in the Assessment area (U.S. EPA 1995).

Figure 1.6 shows which counties have the largest releases of nitrogen oxides from anthropogenic sources. The areas with high annual emissions correspond to the larger cities within or outside the Assessment area including Little Rock, AR; St. Louis, MO; Kansas City, MO; Tulsa, OK; and Dallas, TX. Within the Assessment area, most of the county-level emission estimates are low or below average in comparison to other counties in the United States. Figure 1.6 does not include emission estimates of nitrogen oxides from natural sources. The 1995 emissions from natural sources were low or below average throughout most of the Assessment area (fig. 1.7).

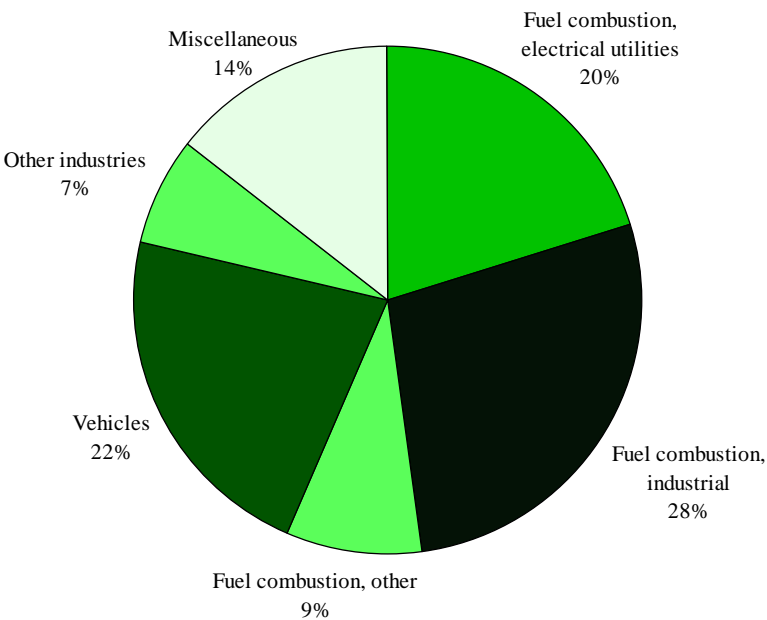


Figure 1.5—Emissions of nitrogen oxide (NO_x) by source categories, based on 1994 data (U.S. EPA 1995).

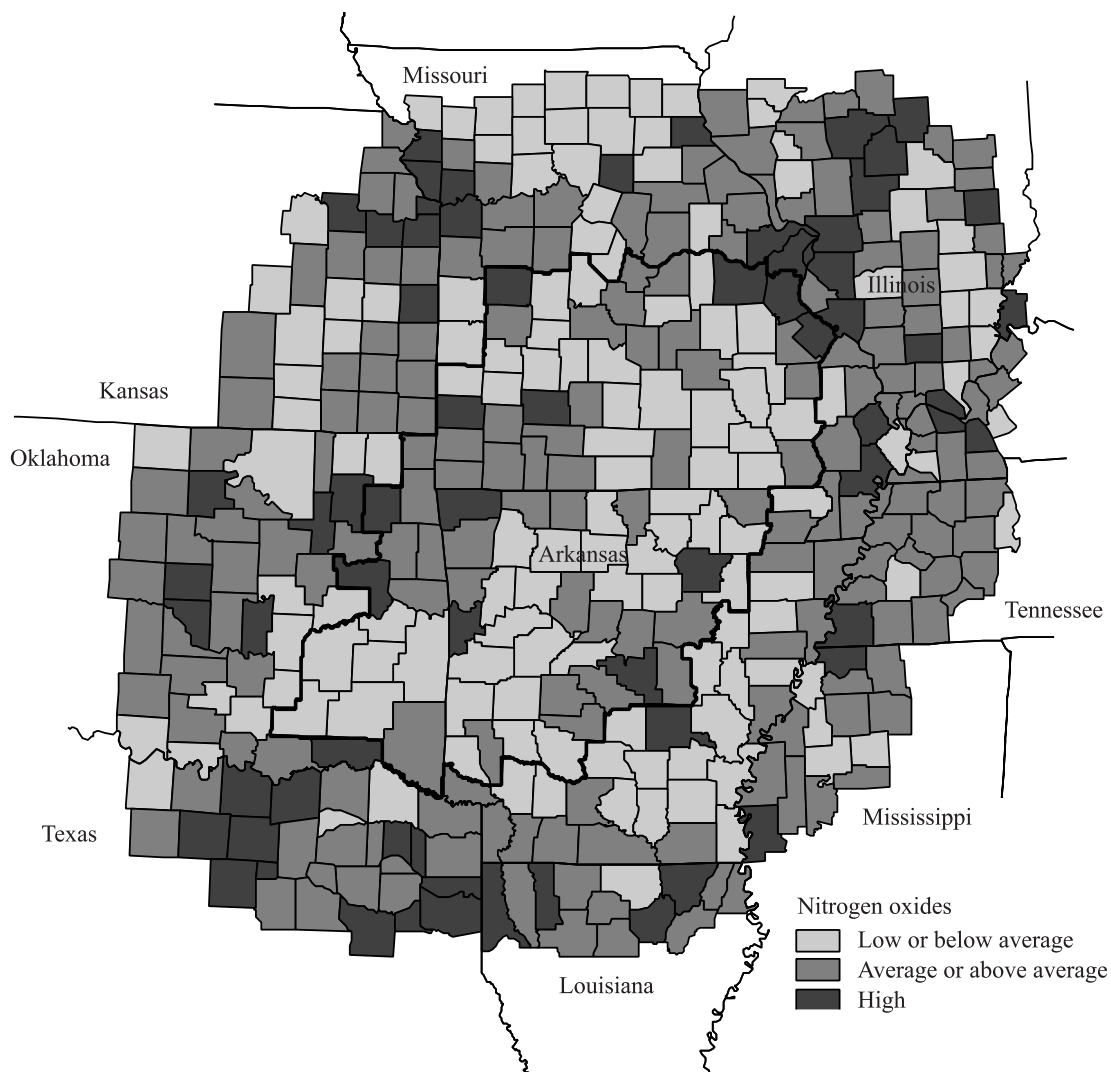


Figure 1.6—Estimates of human-caused nitrogen oxide (NO_x) emissions in Assessment area and surrounding counties in 1994 (U.S. EPA 1995).

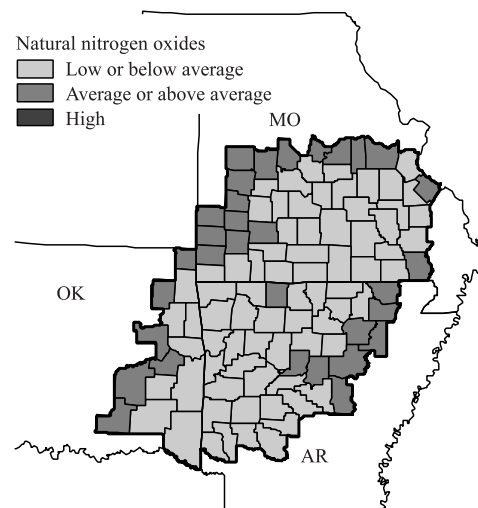


Figure 1.7—Estimates of natural nitrogen oxide (NO_x) emissions in Assessment area counties in 1995.

Volatile Organic Compounds

Volatile organic compounds represent a wide range of organic chemicals that are emitted into the atmosphere. Combined with nitrogen dioxide, these chemicals contribute to the formation of ground-level ozone. Trees are the primary source of naturally produced volatile organic compounds (Placet and others 1991), and much of the Assessment area is forested and has high natural emissions (see fig. 1.8) compared to other counties in the United States. As in the rest of the Nation, motor vehicle use is the main human (anthropogenic) source of volatile organic compounds, accounting for 37 percent of the total emissions (U.S. EPA 1995) (fig. 1.9). Solvent utilization (27 percent) and processes at petroleum and related industries (14 percent) also release volatile organic compounds within 120 mi of the receptors. Figure 1.10 shows a wide range of anthropogenic emissions from counties within 120 mi of the receptors; the highest emissions of volatile organic compounds occur near cities such as Dallas, TX; St. Louis, MO; and Memphis, TN.

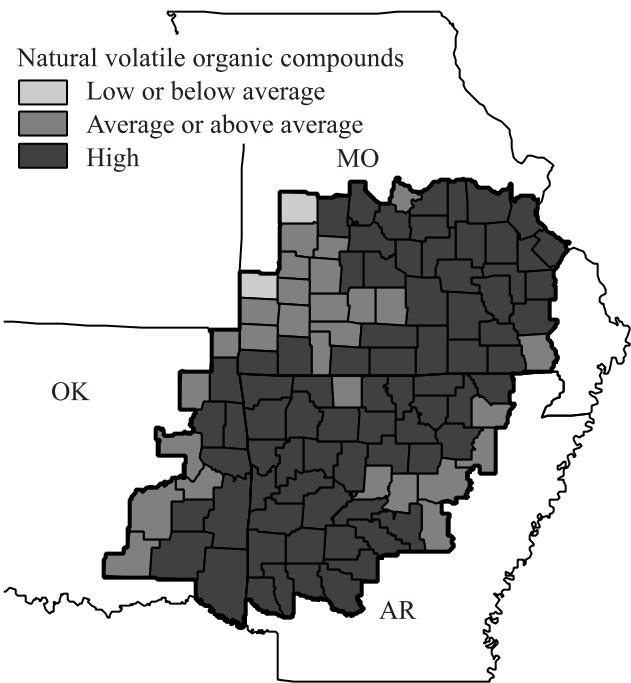


Figure 1.8—Estimates of natural volatile organic compound emissions in Assessment area counties in 1995.

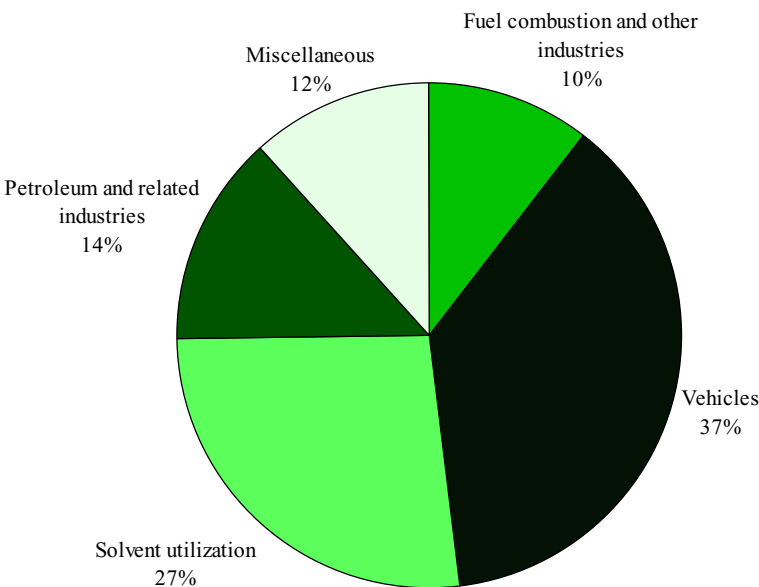


Figure 1.9—Sources of volatile organic compound emissions in 1994 (U.S. EPA 1995).

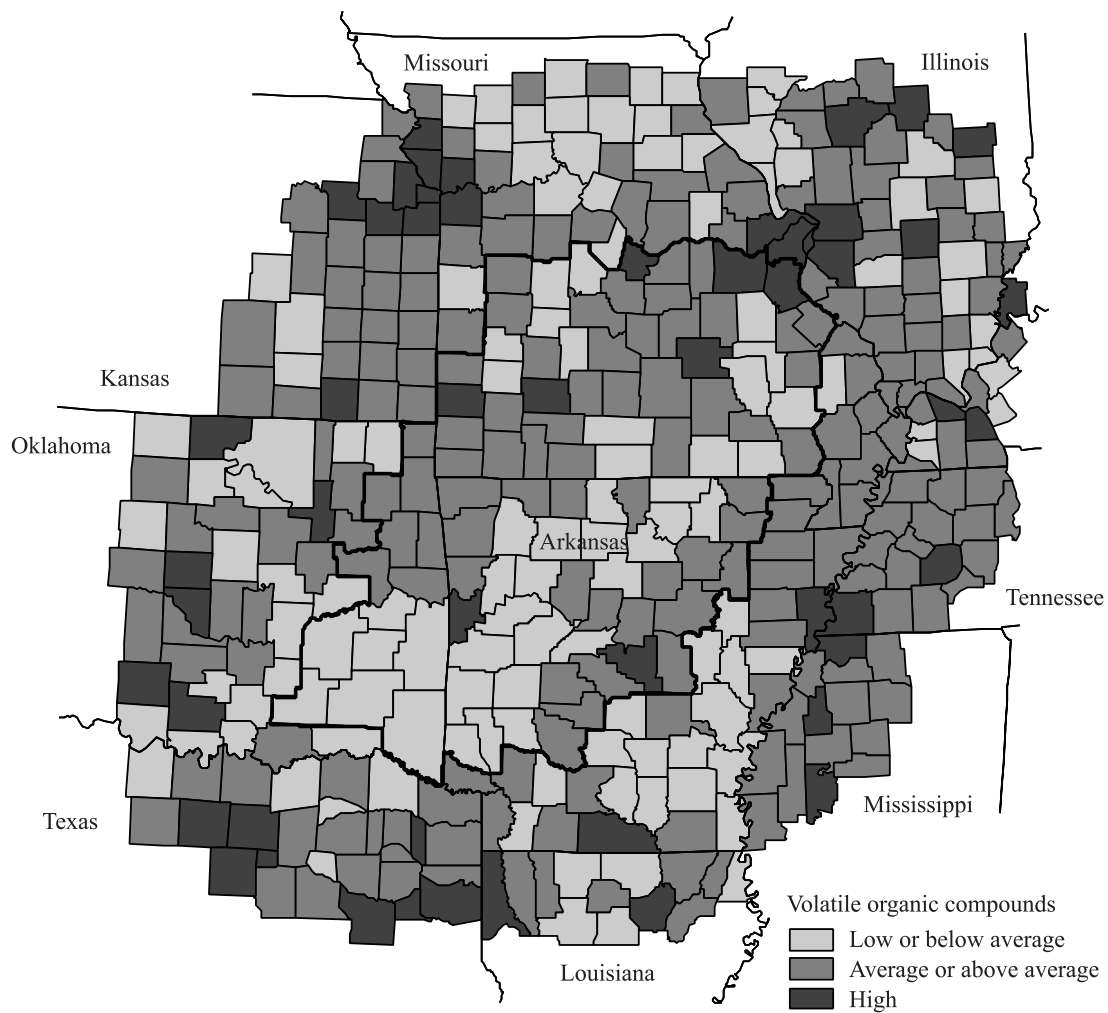


Figure 1.10—Estimates of human-caused volatile organic compound emissions in Assessment area and surrounding counties in 1994 (U.S. EPA 1995).

Sulfur Dioxide

Sulfur dioxide is a gas transformed in the atmosphere into secondary pollutants called sulfates, the main contributors to visibility reduction and acid deposition. Electrical utilities are the largest source of sulfur dioxide affecting the Highlands (72 percent) (fig. 1.11), which is consistent with the national pattern (U.S. EPA 1995). There are very few emissions of sulfur dioxide from natural sources in the Assessment area. As with nitrogen oxides or volatile organic compounds, the counties with the largest emissions are near the largest cities (fig. 1.12).

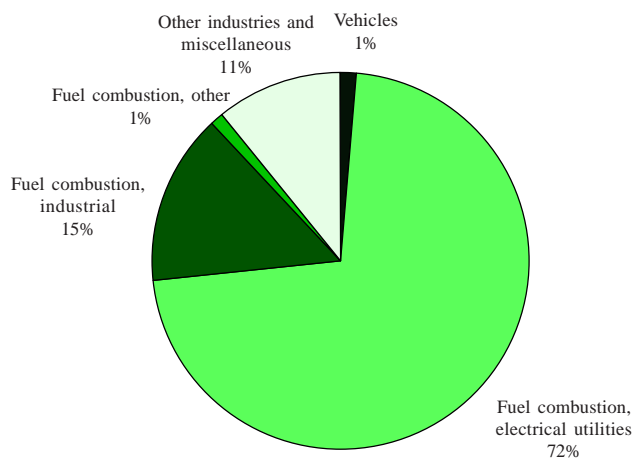


Figure 1.11—Sources of sulfur dioxide (SO₂) emissions in 1994 (U.S. EPA 1995).

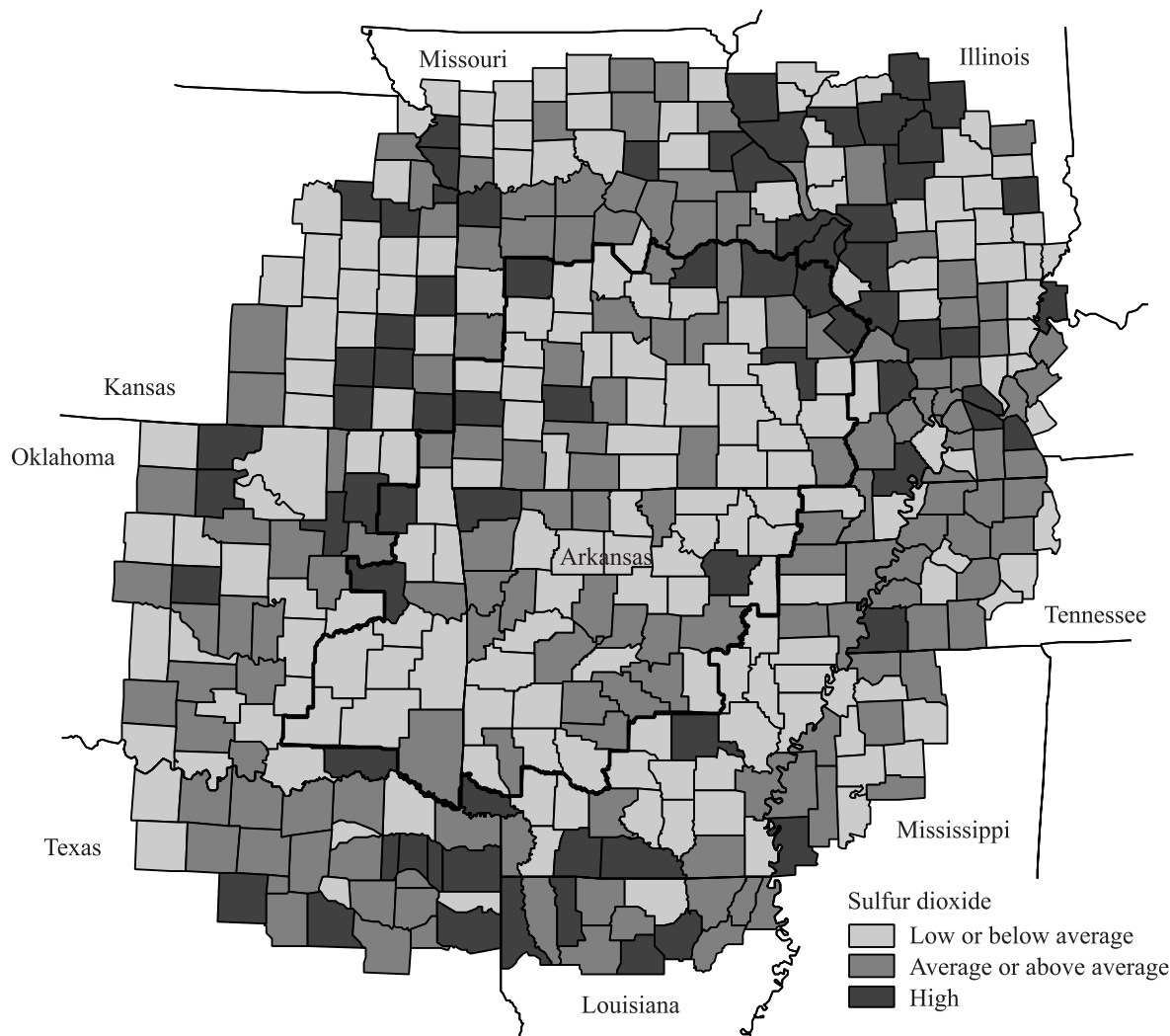


Figure 1.12—Estimates of human-caused sulfur dioxide (SO₂) emissions in Assessment area and surrounding counties in 1994 (U.S. EPA 1995).

Pollution Exposure Index Results

The Atmospheric Team used two approaches to identify which areas receive the greatest exposure to pollutants: (1) ambient monitoring data and (2) a statistical approach. The team found that there were few ambient monitoring sites across the Assessment area, which is the case in rural areas such as the Ozark-Ouachita Highlands. With little data, it is difficult to interpret pollution patterns, so the team chose an additional approach. They considered using an atmospheric dispersion model to predict the transformation of primary pollutants (such as sulfur dioxide) and where the secondary pollutants (such as sulfates) are likely to be the greatest. There are numerous complex atmospheric models available, but the cost was prohibitive. Therefore, the Atmospheric Team chose to use the statistical PEI model (Miller 1997), described earlier, to identify areas with the greatest pollution exposure.

The PEI values are calculated based upon: (1) the annual emission of the specific pollutant, (2) the distance between the source and receptor, (3) the frequency of winds blowing from the source toward the receptor (assuming a straight-line windflow), and (4) the degree to which hills or mountains impede the windflow. The results from the PEI model do not predict pollutant deposition of secondary pollutants (such as sulfates or ozone). Therefore, the model results should not be used to say that impacts are occurring from a specific pollutant. Furthermore, the PEI uses the direction frequency of ground level winds, which is usually not reliable at locations far from a measurement site. Atmospheric dispersion models use the results of complex meteorology modeling to estimate wind directions and speeds at ground level and various heights in the atmosphere. The PEI model does not take into account local topographic effects on wind fields; therefore, a person must be cautious when making any strong statements about a specific spot in the Assessment area. The model is useful because it predicts which portions of the region are most likely to have the greatest pollution exposure from anthropogenic sources, and it may be useful in locating where further monitoring should be conducted.

As has been noted, the greatest source of PM_{10} emissions is fugitive dust (fig. 1.4) in the western and northern counties within the Assessment area (fig. 1.3). Therefore, the PEI model predicts that PM_{10} exposures

are likely to be greatest along the western portions of the Assessment area (fig. 1.13). PM_{10} exposures in the air are likely to be less in the central portions of the Assessment area because particles transported eastward by predominately westerly winds are likely to deposit from the atmosphere near their sources (fig. 1.13).

The team did not have emission estimates from natural sources of volatile organic compounds and nitrogen oxides within 120 mi of the receptors (fig. 1.2). Therefore, only anthropogenic emission estimates for volatile organic compounds and nitrogen oxides were used as input into the PEI model. Assessing where these pollutants have the potential for the greatest impact is difficult since the PEI model does not include transformation of these emissions to ground-level ozone or nitrate deposition. The PEI results for nitrogen oxides and volatile organic compounds are shown in figures 1.14 and 1.15, respectively. The model simulations suggest that anthropogenic exposure to nitrogen oxides and volatile organic compounds is lowest in the interior and highest near the perimeter of the Assessment area—particularly near the east-central, west-central, and northeastern perimeters.

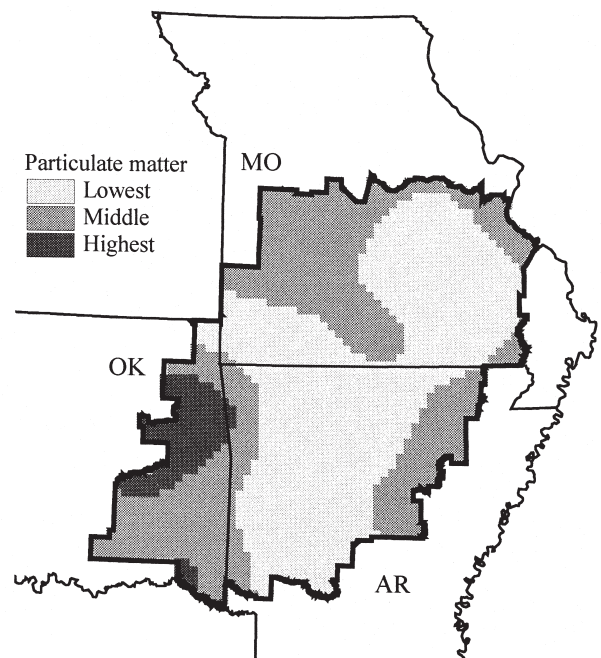


Figure 1.13—Pollution Exposure Index modeling results using 1994 particulate matter (PM_{10}) emissions data.

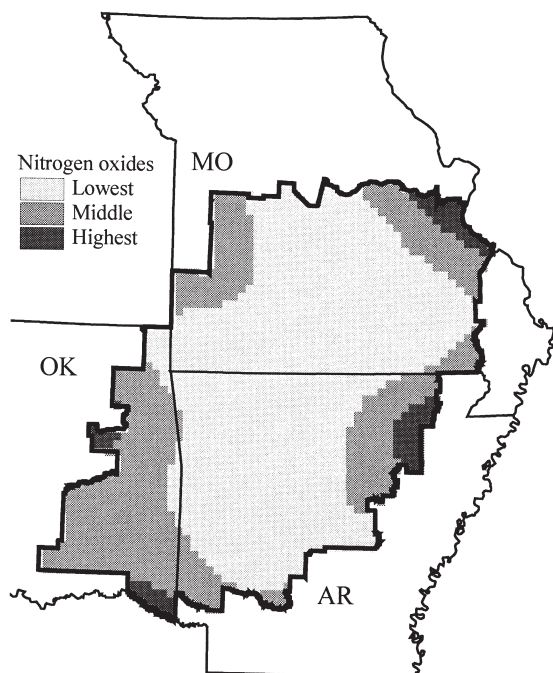


Figure 1.14—Pollution Exposure Index modeling results using 1994 human-caused nitrogen oxide (NO_x) emissions data.

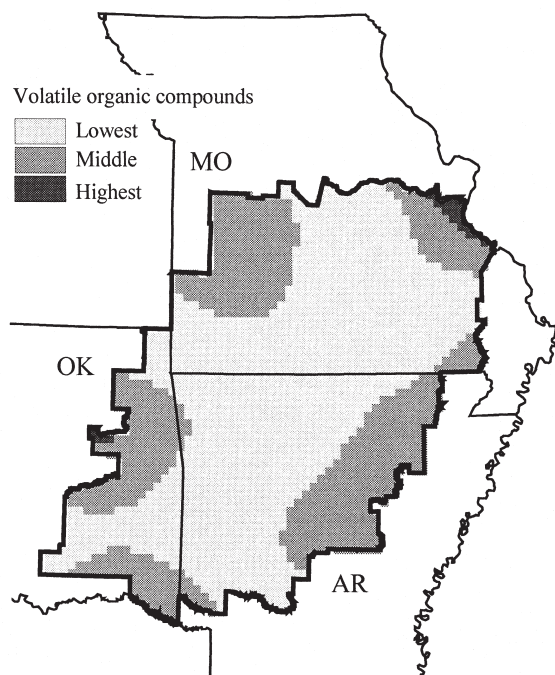


Figure 1.15—Pollution Exposure Index modeling results using 1994 human-caused volatile organic compound emissions data.

Chameides and Cowling (1995) suggest that ozone formation is likely to be greater downwind of nitrogen oxide sources because volatile organic compounds typically are not a limiting factor in rural areas of the Southern United States. The PEI results for nitrogen oxides (fig. 1.14) suggest ozone exposures are likely to be greatest in the Ozark-Ouachita Highlands downwind of St. Louis, MO; Little Rock, AR; Dallas, TX; and Tulsa, OK.

The Atmospheric Team decided the PEI results should not be used to predict where sulfate and nitrate deposition would be the greatest because the total deposition in a given area is the sum of the amount in the rainfall, dry fall (usually seen as haze), and cloud water. Furthermore, fine particles (2.5 microns or smaller) of sulfates and nitrates travel very long distances before settling to the ground. The PEI results in figures 1.14 and 1.16 show where nitrogen and sulfur (such as nitrogen oxide and sulfur dioxide) exposures may be the greatest. As mentioned previously, exposures to nitrogen oxide emissions may be the greatest downwind of several large cities within or near the Assessment area (fig. 1.14). Exposure to sulfur compounds is likely to be greatest in the northeastern portion of the Assessment area near St. Louis, MO.

One consistent pattern from the PEI model results is evident (figs. 1.13 to 1.16). The modeling results of the emissions from the four primary pollutants of interest indicate a pattern throughout a large portion of the Assessment area that suggests that pollution exposures should be less there, whereas they appear to be higher close to the boundary.

Emission Trends

The Clean Air Act (CAA) is the primary means by which the American public's health and welfare (as they relate to air pollution) are protected. Implementation of the CAA and its amendments since 1977 has resulted in significant reductions for several primary pollutants (fig. 1.17). Nationally, particulate matter emissions from stationary sources decreased significantly between 1940 and 1994 (fig. 1.17), but total PM₁₀ emissions have not decreased because a large portion is from fugitive dust sources (U.S. EPA 1995). Therefore, total PM₁₀ emissions are predicted to remain constant in the future because there are no initiatives that would significantly reduce fugitive dust emission.

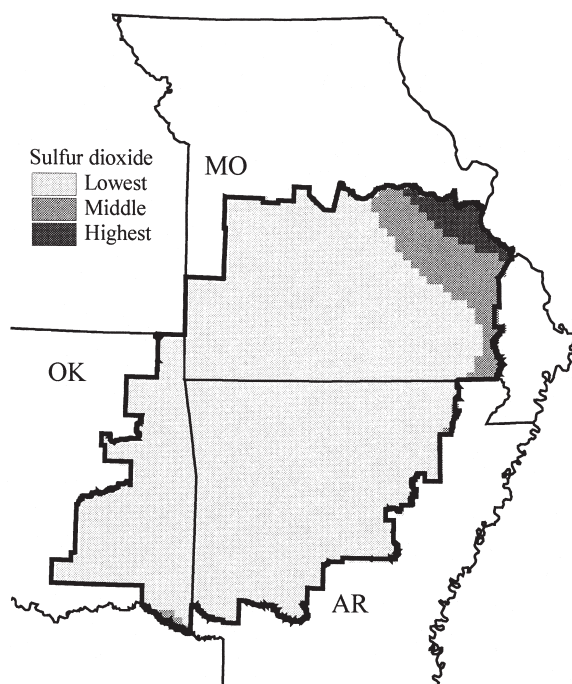


Figure 1.16—Pollution Exposure Index modeling results using 1994 sulfur dioxide (SO₂) emissions data.

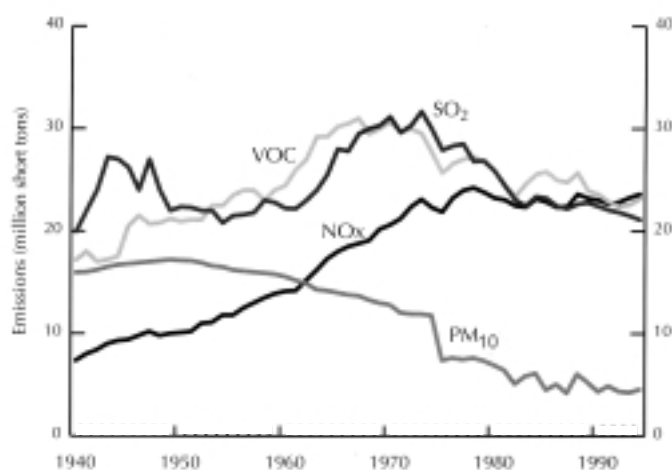


Figure 1.17—Trends in national emissions of nitrogen oxides (NO_x), volatile organic compounds (VOC), sulfur dioxide (SO₂), and particulate matter (PM₁₀, nonfugitive dust sources) from 1940 through 1994 (U.S. EPA 1995).

Nationally, emissions of nitrogen oxides rose from 1940 through 1994 (fig. 1.17). Most of this growth is attributed to an increase in the number of vehicle miles traveled annually as well as increases from electrical utilities (U.S. EPA 1995). Compliance with Title IV of the 1990 CAA amendments will reduce nitrogen oxide emissions from electrical utility boilers by 2 million tons from the 1980 level (U.S. EPA 1996), but there is no Federal law to keep overall nitrogen oxide emissions at or below 1980 levels. Recently, the EPA notified State and local air pollution control agencies in 22 Eastern States that further nitrogen oxide reductions are necessary for urban areas to reach the national standards for ground-level ozone concentrations. Therefore, several States (Illinois, Kentucky, Missouri, and Tennessee) near and within the Ozark-Ouachita Highlands are likely to reduce nitrogen oxide emissions by an additional 35 to 43 percent. There is a high likelihood these reductions will be achieved by the electrical utilities, but each State will determine which nitrogen oxides sources will make future reductions.

Nationally, emissions of volatile organic compounds increased between 1940 and 1970; subsequently, they have decreased (fig. 1.17). The team is uncertain about the direction of future emission levels of volatile organic compounds because they are difficult to predict. Emissions could decrease as a result of (1) compliance with the CAA amendments of 1990, (2) further decreases in the use of solvents (used to clean equipment), and (3) an increase in the amount of water-based compounds (such as paints) that have low amounts of volatile organic compounds. These reductions have the potential to be negated if the number of vehicle miles traveled continues to increase in the future.

Sulfur dioxide emissions increased nationally between 1940 and 1970; since then, they have steadily decreased and are now approximately at 1940 levels (fig. 1.17). Compliance with the 1990 CAA amendments will reduce sulfur dioxide emissions by 10 million tons below the 1980 level (U.S. EPA 1996), and there will be a cap on emissions from utility and industrial sources.

Implications and Opportunities

To discuss air quality within the Assessment area, the Atmospheric Team needed to understand where pollution releases are the greatest and what types of sources are

emitting specific pollutants. The team compiled county-level data that can be used by land managers and others to see how a proposed action (e.g., a community in the Assessment area is looking for a new industry or prescribed fire is needed to reduce undergrowth) may influence emissions from a specific county. Emissions estimates are critical for such determinations. Future assessments should gather emission estimates for the

primary pollutants considered in this report, as well as particulate matter 2.5 microns and smaller ($PM_{2.5}$) in size. Also, further work after this Assessment, or a future assessment, could use one or more complex atmospheric dispersion models to gain a more complete understanding of how the emissions from an area will impact a downwind region.

Chapter 2: Particulate Matter (PM₁₀) in the Air

Question 2: What is the status of particulate matter in the Ozark-Ouachita Highlands?

The previous chapter provided a description of some of the relevant pollutant emissions characteristics within the Assessment area, including particulate matter. This chapter provides a more indepth analysis of the typical seasonal particulate matter concentration patterns in the atmosphere over the Assessment area that result from the emissions patterns described in Chapter 1.

Particulate matter (PM₁₀) as an air pollutant consists of those particles suspended in the atmosphere that are 10 microns or smaller in diameter. The most important constituents of particulate matter are particles 2.5 microns in diameter (PM_{2.5}) or smaller. These tiny particles can be breathed into human lungs and create serious health problems (e.g., respiratory ailments and asthma). White (1995) of the American Lung Association maintains that there is no tolerance level below which particulates do not affect human health. Stated another way—any increase in particulate concentration

can cause an increase in human health problems. These problems have been triggered at concentrations well below current National Ambient Air Quality Standards (NAAQS) (White 1995).

Particulates come from many sources: industry, electrical power production, internal combustion engine exhaust, dust from natural and artificial sources, smoke from agricultural and forestry burning, and wildland fires. The U.S. Environmental Protection Agency (EPA) categorizes sources of particulate matter emissions that are 10 microns or smaller in diameter (PM₁₀) as point sources (smokestack emissions) or fugitive process sources (e.g., dust, leaks, uncontrolled vents). Fugitive dust is also generated by wind erosion, agricultural tilling, mining, construction, and both paved and unpaved roads (U.S. EPA 1996).

Even though industrial production has increased nationally during recent decades, pollution control equipment has dramatically reduced PM₁₀ emissions from industrial processes (fig. 1.17). Figure 2.1 illustrates that in 1970, smokestacks generated over 12 million tons of PM₁₀ particles, while in 1995, they produced only about 2.5 million tons (U.S. EPA 1996). The Clean Air Act

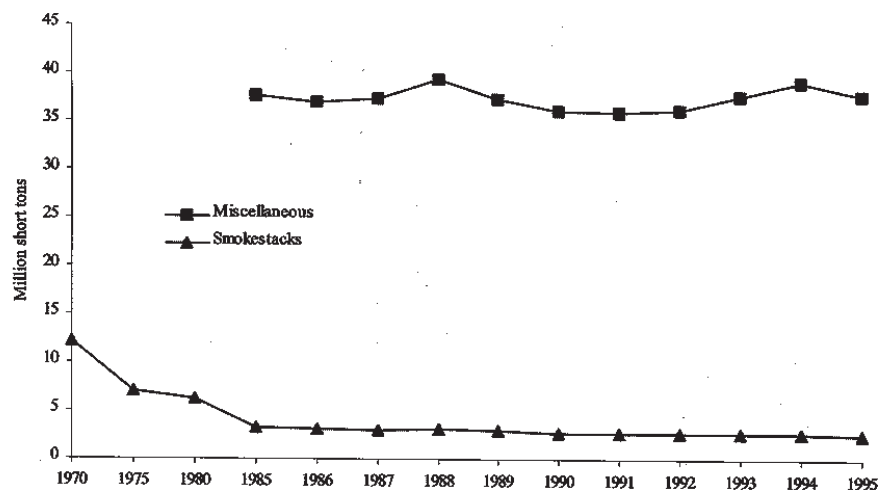


Figure 2.1—National smokestack and miscellaneous particulate matter (PM₁₀) emissions (in million short tons) from 1970 through 1995 (U.S. EPA 1996).

(1970) and its amendments (1977 and 1990) encouraged this abatement.

According to the guidelines of the NAAQS, PM₁₀ concentrations at any location are not to exceed 150 micrograms per cubic meter ($\mu\text{g m}^{-3}$) during a 24-hour period. The NAAQS also limit the average annual exposure of PM₁₀ at any location to 50 $\mu\text{g m}^{-3}$. In July 1997, the EPA implemented a new ambient air quality standard based on particulate matter 2.5 microns or smaller in diameter (PM_{2.5}). This new standard states that the average annual and 24-hour concentrations are not to exceed 15 $\mu\text{g m}^{-3}$ and 65 $\mu\text{g m}^{-3}$, respectively, at monitoring sites that represent a large-scale area and are not related to a specific source.

In addition to its potential effect on human health, particulate matter reduces visibility (discussed in the next chapter). Within the Assessment area, all areas presently meet the PM₁₀ NAAQS. There are no chronic particulate matter (PM) problems on or near national forest lands in Arkansas or Oklahoma. In southern Missouri, however, the charcoal industry has created a locality with reoccurring days of high PM concentrations (Braun 1996). The State is looking into this situation.

Key Findings

1. Particulate matter concentrations (PM₁₀) show a definite seasonal trend over the Assessment area. The highest concentrations between 1991 and 1995 were during the summer months, with an average period concentration of 33.05 micrograms per cubic meter ($\mu\text{g m}^{-3}$); the average winter concentration was 19.84 $\mu\text{g m}^{-3}$.
2. Rural areas have lower PM₁₀ concentrations than urban areas.
3. There is a spatial distribution of PM₁₀ across the Assessment area, with the lowest annual average PM₁₀ concentrations occurring in western Arkansas.
4. The Assessment area is well within the National Ambient Air Quality Standards (NAAQS) for PM₁₀. Implementation of the new PM_{2.5} regulations may create a challenge to prescribed burning programs of farmers and land management agencies such as the USDA Forest Service.

Data Sources and Methods of Analysis

Most data analyzed for this Assessment are from the EPA's Aerometric Information Retrieval System (AIRS). In addition, the team used data from the Interagency Monitoring of Protected Visual Environment (IMPROVE) monitoring network.

The AIRS data base is the national data storage system for all Criteria Pollutants. Data were obtained from AIRS sites both inside and within 100 miles (mi) of the Assessment area boundary. The EPA sets rigid data collection standards and assures the quality of all data entered into the system. Because the EPA changed PM standards in 1987 from measurement of total suspended particles (TSP) to PM₁₀, the team decided to avoid using TSP data and instead chose PM₁₀ data from 1991 to 1995 because all sites were monitoring with PM₁₀ equipment by 1991. The point data were displayed using the Geographic Information System (GIS) software called ArcInfo®. These data were analyzed across the Assessment area using the "inverse distance weighting method" (Burrough 1988) and then displayed in a grid format. Each grid was assigned a value. These grid values represent estimated rather than measured values. This limitation needs to be considered when making assertions or recommendations using these or similar data.

Patterns and Trends

Table 2.1 shows the seasonal, annual, and period means of PM₁₀ concentrations over the entire Assessment area based on observational data from the AIRS network (mainly urban areas). The numbers in table 2.1 represent averages of all the PM₁₀ monitors inside the Assessment area from 1991 through 1995. The seasonality of PM₁₀ is clearly evident in table 2.1, with the average PM₁₀ concentrations at AIRS monitoring sites over the entire Assessment area typically increasing from wintertime minimum values to summertime maximum values. Figure 2.2 shows the typical, large-scale spatial distributions of PM₁₀ concentrations for each season over the Assessment area based solely on AIRS network data. Because most observation sites in the AIRS network are in urban areas where PM₁₀ concentrations tend to be higher than in rural settings, the interpolated spatial patterns of PM₁₀ concentrations across the Assessment area most likely overestimate nonurban PM₁₀ concentrations. Nevertheless, the spatial patterns shown in figure 2.2 provide a general indication of the impact of urban PM₁₀ emission sites on PM₁₀ concentrations in the Assessment area.

The interpolated mean winter PM₁₀ data from the AIRS network shown in figure 2.2 indicate that most PM₁₀ concentrations in the Assessment area are less than 22.5 µg m⁻³ (based on 1991 to 1995 data). Concentrations tend to increase during the spring months over parts of the Assessment area, particularly over the western and eastern sections of the Assessment area as well as in southern Missouri (fig. 2.2). The interpolated

AIRS PM₁₀ data indicate average spring concentrations in these regions are about 22.51 to 27.5 µg m⁻³, although actual mean concentrations in some of the more rural locations in these regions are probably less. In central Arkansas, average springtime concentrations are generally lower. The highest particulate matter concentrations throughout the Assessment area are usually found during the summer months (fig. 2.2). The interpolated AIRS data suggest summertime PM₁₀ concentrations in the Assessment area often exceed 27.5 µg m⁻³ (especially in urban areas). Particulate matter concentrations tend to decrease during the fall months, although they are still relatively high compared to the wintertime minimum concentrations (fig. 2.2). The far northern sections of the Assessment area experience the most dramatic decrease in PM₁₀ concentrations from the summer to fall seasons. Based solely on AIRS network data, the annual mean PM₁₀ concentrations for the entire period over most of the Assessment area range from 22.51 to 27.5 µg m⁻³ (fig. 2.3), well within the present NAAQS of 50 µg m⁻³.

The seasonality of PM₁₀ is partly due to increased dust production in the spring and summer months compared to the winter months—especially during dry years—as well as increased power production for air conditioning. Also, emissions from automobiles and other internal combustion engines increase during the summer. Another source of particulate matter is the natural increase in atmospheric moisture (water vapor) during the summer. Certain kinds of particles, especially sulfates, are hygroscopic (meaning they attract water), which increases their weight. The AIRS data also appear to indicate the effects of agricultural tillage. For example, in March, higher PM₁₀ values show up in southwestern Missouri during tillage; in April and May, these higher concentrations are in the agricultural areas in Arkansas (tillage occurs later because the area retains wetness). (Monthly maps are available upon request from the Forest Service in Arkansas—see information inside the front cover of this report.)

Figure 2.4 illustrates the average PM₁₀ mass concentrations in µg m⁻³ from 1992 to 1995 at sites in the IMPROVE network. These are Class I wilderness areas—wildernesses that are larger than 5,000 acres and national parks larger than 6,000 acres in existence on or before August 7, 1977. Class I areas are defined by the Clean Air Act (CAA) amendments of 1977 as having “special protection” from effects of air pollution because

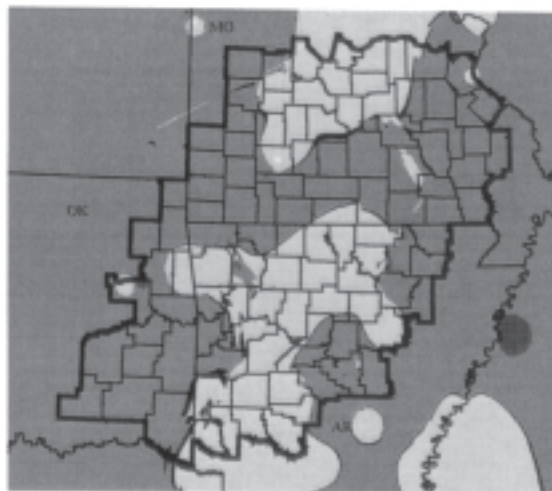
Table 2.1—Average PM₁₀ concentrations (in µg m⁻³) in the Assessment area by season, year, and 5-year period

Season	1991	1992	1993	1994	1995	1991– 1995
Winter	21.68	21.04	19.47	19.74	18.33	19.84
Spring	23.75	25.05	22.32	25.53	24.69	24.08
Summer	34.04	31.29	34.12	25.47	32.81	33.05
Fall	26.74	23.52	21.61	23.59	28.09	24.77
Annual	26.35	25.20	24.29	25.43	25.93	25.47

PM₁₀ = particulate matter 10 microns or smaller; µg m⁻³ = micrograms per cubic meter.



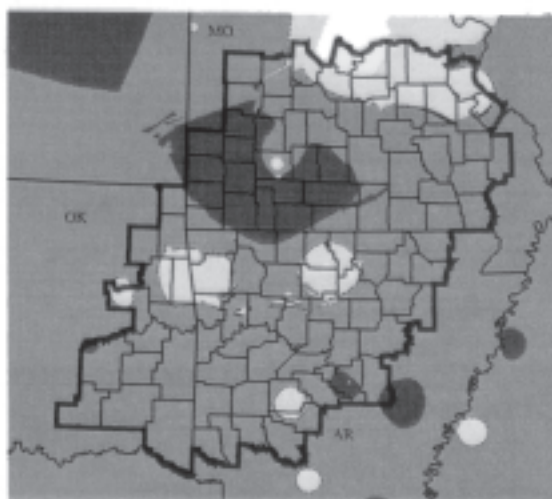
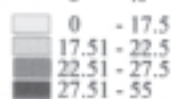
Average PM_{10} values for winter, 1991-1995



Average PM_{10} values for spring, 1991-1995



Average PM_{10} values for summer, 1991-1995



Average PM_{10} values for fall, 1991-1995



Figure 2.2—Average PM_{10} values ($\mu g\ m^{-3}$) during winter, spring, summer, and fall from 1991 through 1995.

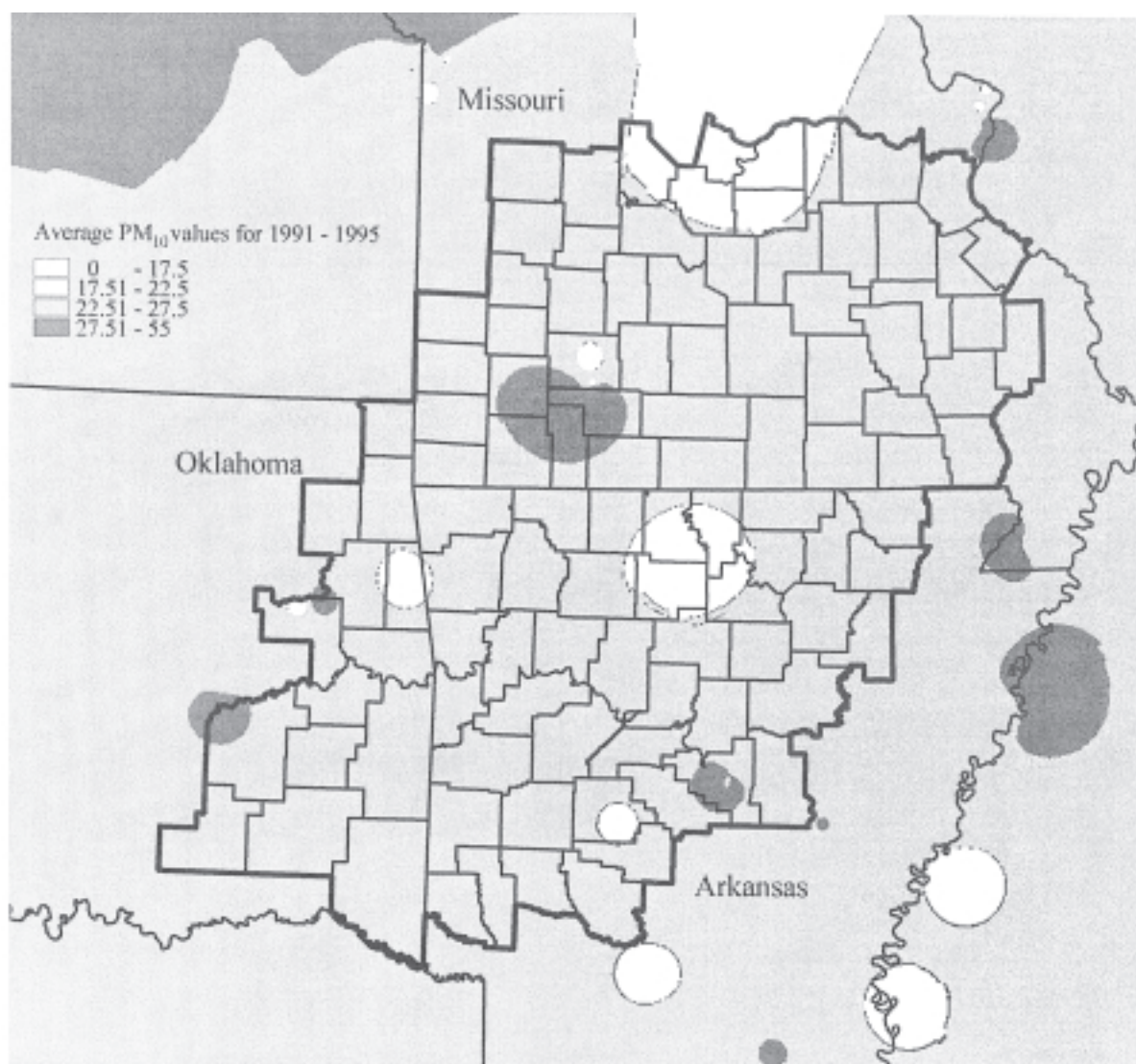


Figure 2.3—Average PM_{10} values ($\mu g m^{-3}$) for the 1991 through 1995 period.

of their “air-quality related values (AQRV’s),” i.e., water quality, native vegetation, ecosystem integrity, and visibility. Figure 2.4 indicates that the annual mean PM_{10} concentrations in the Class I areas within the Assessment area are between 15 and 18 $\mu g m^{-3}$ (average concentration at Deer, AR—a nonurban area—is 17.4 $\mu g m^{-3}$). Comparing these values with the annual mean PM_{10} concentration in urban areas (AIRS network data) within the Assessment area (25.47 $\mu g m^{-3}$ from table 2.1) suggests that the rural forested regions in the Assessment area have about 30 to 40 percent less particulate matter than the urban areas when averaged over an entire year.

Prescribed burning is currently a minor source of particulate emissions in the Highlands area on a yearly basis. The 1995 level of managed burning reported by the EPA produced 538 short tons of emissions, accounting for 1.3 percent of the national total PM_{10} emissions (U.S. EPA 1996). These emissions include silvicultural and agricultural burning. On shorter time scales, however, prescribed burning can result in significant local emissions of particulate matter. Two studies have been reported in the Southern States where portable PM_{10} monitors were set up adjacent to prescribed fires for 2 to 12 hours. The Florida Department of Environmental Protection and the

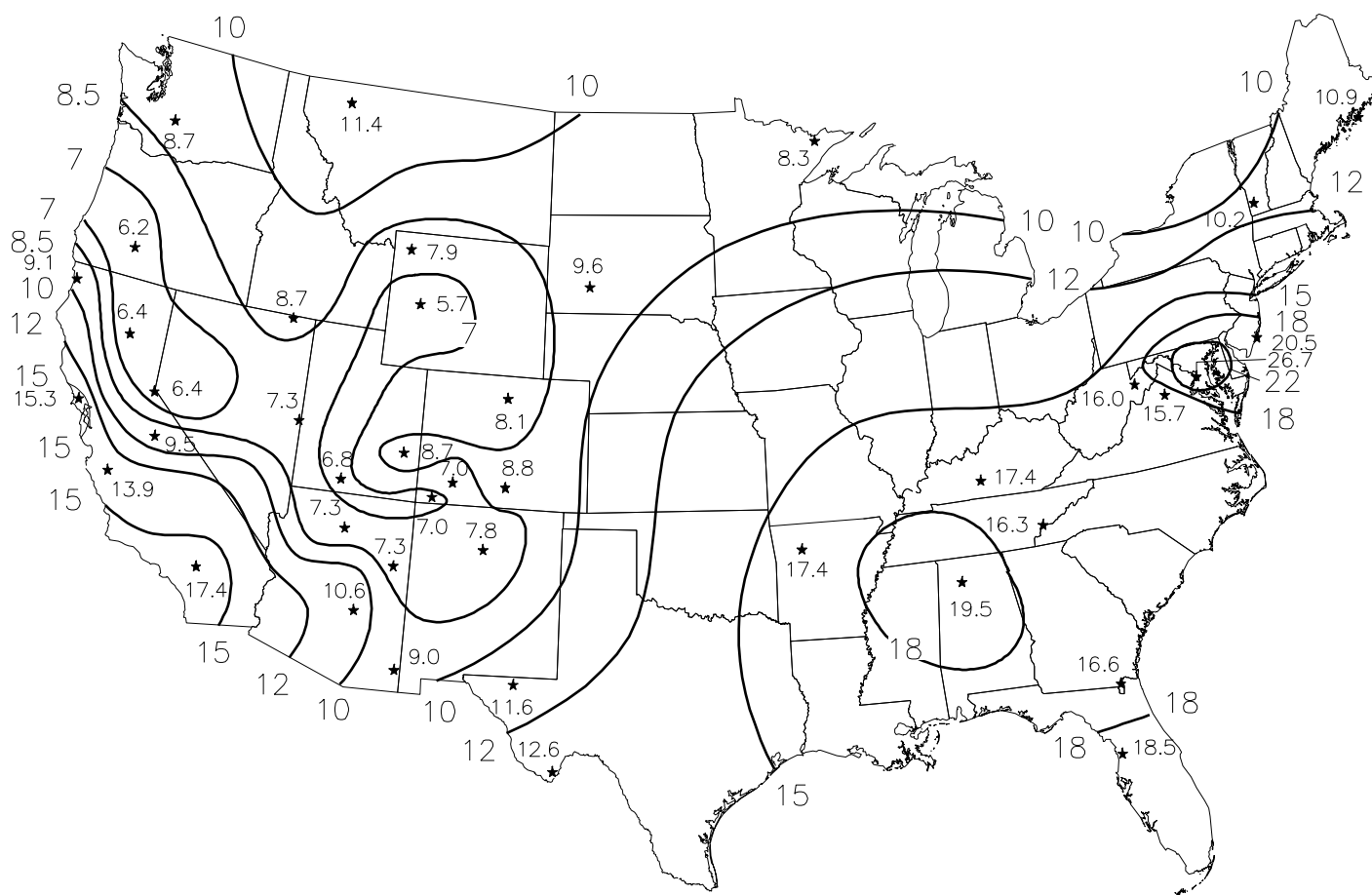


Figure 2.4—Average PM₁₀ mass concentration (µg m⁻³) for each site in the IMPROVE network for the 1992 through 1995 period (CIRA 1997).

Apalachicola National Forest conducted one study (FL DEP 1993), and the Texas Forest Service and the National Forests in Texas conducted the second (Hunt and others 1994).

In 90 percent of the cases from these prescribed fire studies, particulate-matter concentrations were less than 150 µg m⁻³ when measured more than 1 mi from the control line of the prescribed fire. The standard was usually maintained as close as 1 mi from the control line. However, the likelihood of exceeding the 24-hour NAAQS for particulate matter of 150 PM₁₀ µg m⁻³ increased as fire control lines were approached, with only a few cases noted where the 24-hour standard was not exceeded at the control line. Both studies showed that prior to burning, the PM₁₀ concentrations in the air mass were 15 to 30 µg m⁻³, well below both the annual and 24-hour standards. The PM₁₀ concentrations associated with prescribed

burns are dependent on weather, type and amount of fuel, fuel moisture, and the intensity and duration of the burn. These conditions are variable in time and space over the area of the burn and downwind of the burn.

Implications and Opportunities

Any future trends in particulate matter concentrations over the Assessment area will likely be influenced by the new, stricter NAAQS for PM_{2.5}. The smaller particle is considered a health hazard since it can be breathed deeply into the lungs. The smaller particle also is more efficient at scattering light, so reductions for health concerns will also improve visibility. Any improvements in the exhaust systems of internal combustion engines, both gasoline and diesel, could result in emission reductions of

particulate matter. Also, dust abatement on gravel roads may become necessary in some areas. Until the $PM_{2.5}$ monitoring system mandated by the new NAAQS provides the data, the impact of the stricter standards on the use of prescribed fire will remain conjecture. It will be approximately 5 years before these data will be available.

How will the new $PM_{2.5}$ regulations impact the use of prescribed fire? Haddow (1990) found that approximately 70 percent of the particulate matter produced by wildland fuels is within the $PM_{2.5}$ size class. The proposed regulations call for the 24-hour standard to be less than $65 \mu g m^{-3}$ and the annual average to be less than $15 \mu g m^{-3}$. Figure 2.5 illustrates that the 1992 to 1995 annual average concentration of fine mass particles (diameter of 2.5 microns or smaller) was between 9 and $11 \mu g m^{-3}$ over the more rural areas of the Assessment

area based on interpolated IMPROVE network data. These concentrations represent between 60 and 73 percent of the proposed standard annual average of $15 \mu g m^{-3}$ and 18 to 22 percent of the current annual standard of $50 \mu g m^{-3}$. Thus, even with the implementation of the new $PM_{2.5}$ standards, the more rural sections of the Assessment area should still be in compliance if current $PM_{2.5}$ concentration averages continue to characterize the region.

According to Forest Service records, most prescribed burning occurs during March in the Assessment area. Average PM_{10} concentrations in the Assessment area during March (from 1991 through 1995)—when prescribed burning is common—ranged from a minimum of 10 to $20 \mu g m^{-3}$ to a maximum of 30 to $40 \mu g m^{-3}$ (fig. 2.6) with a mean of $22.7 \mu g m^{-3}$ (based on

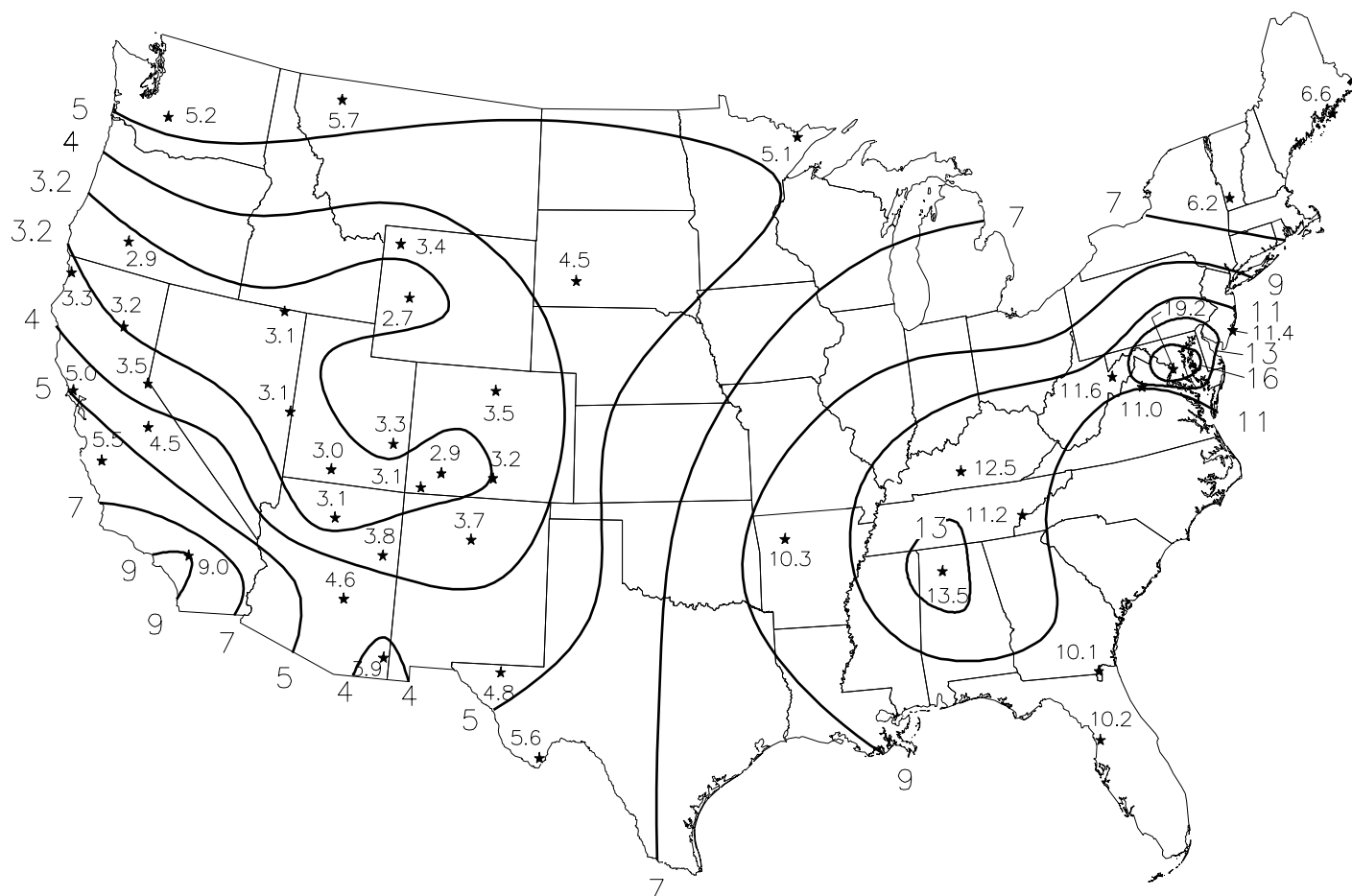


Figure 2.5—Average fine particle mass ($PM_{2.5}$) concentrations ($\mu g m^{-3}$) for each site in the IMPROVE network for the 1992 through 1995 period (CIRA 1997).

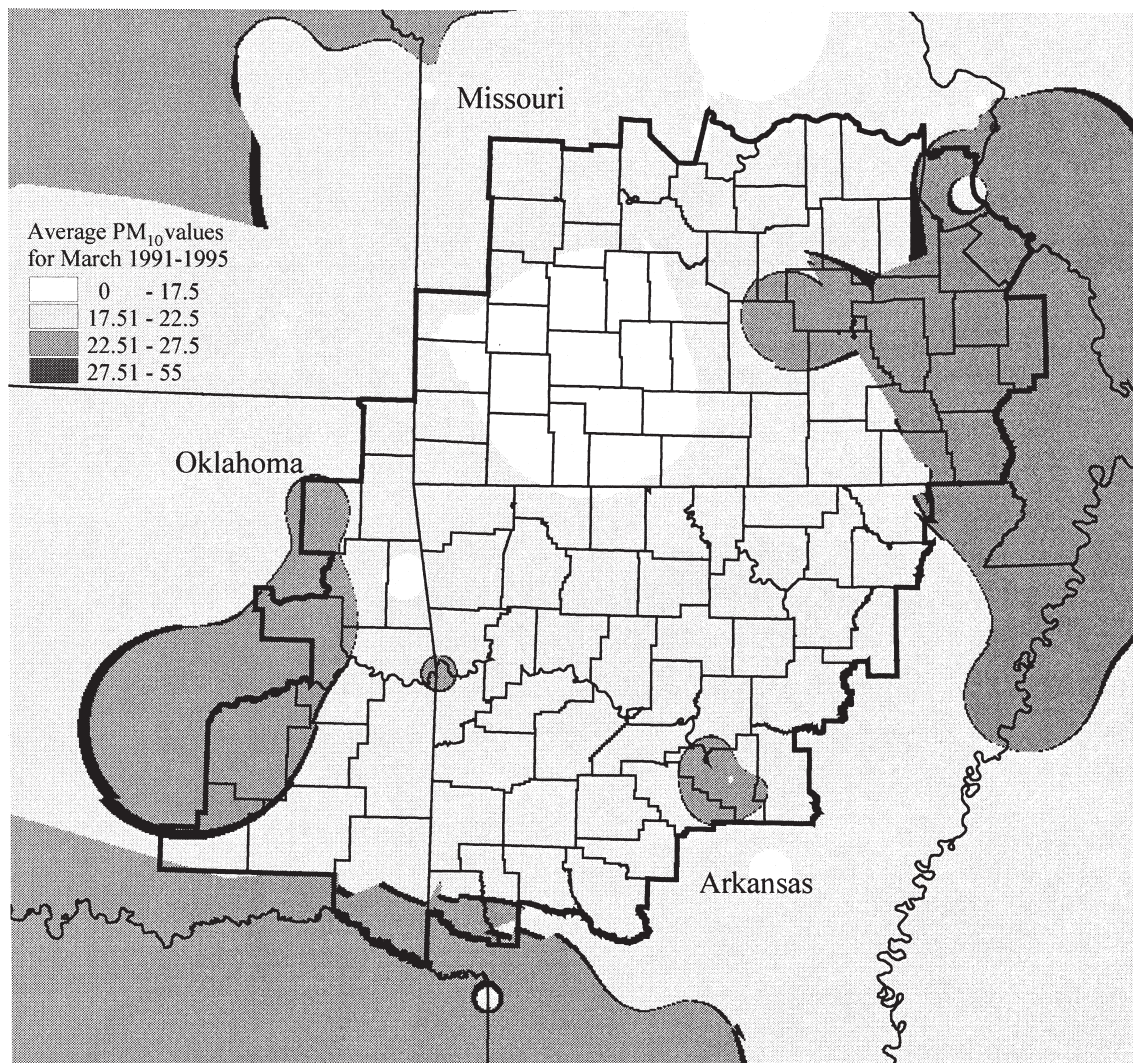


Figure 2.6—Average PM₁₀ concentrations ($\mu\text{g m}^{-3}$) during March for the 1991 through 1995 period.

interpolated AIRS data). If prescribed fire becomes a more widely used land management tool in the Assessment area during the normal prescribed fire season, total PM₁₀ and PM_{2.5} emissions and concentrations in the

atmosphere will likely increase during the springtime. These increases would lead to a more dramatic degradation of air quality from the winter to spring seasons than what is currently observed (fig. 2.2).

Chapter 3: Visibility

Question 3: How good is visibility in the Assessment area; how does air pollution affect visibility?

The Ozark-Ouachita Highlands are blessed with scenic beauty. Visitors and residents want to be able to enjoy the natural sights surrounding them. In fact, one of the reasons most often given for living near or visiting the Highlands is to enjoy the scenery. The clarity of air—or visibility—affects the ability to see the pine and oak covered mountains, rocky bluffs, and scenic streams of the Highlands. In addition to being an important component of the quality of life in the region and a major factor in recreation and tourism, visibility is protected by Federal law. The Clean Air Act (CAA) amendments of 1977 declared “. . . as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas . . .” when such an impairment results from air pollution caused by human activities. Within the Highlands, there are three Class I areas: Caney Creek Wilderness on the Ouachita National Forest, Upper Buffalo Wilderness on the Ozark-St. Francis National Forests, and Hercules Glade Wilderness on the Mark Twain National Forest. (Mingo Wilderness, a Class I area managed by the U.S. Fish and Wildlife Service, lies near the eastern border of the Missouri Ozarks.)

Visibility impairment is most simply described as the haze that obscures clarity, color, texture, and form. Several components interact to determine visibility conditions: (1) the object being viewed, (2) atmospheric conditions influencing the sight path, (3) lighting conditions, and (4) the viewer. Visibility impairment is caused by aerosols (solid or liquid particles dispersed in the air) or gases in the atmosphere that scatter or absorb light. Knowledge of the chemical and physical properties of the

aerosols responsible for visibility impairment can provide insight into the causes of visibility problems. Scattering efficiency for visible light is greatest for particles and aerosols with diameters in the 0.1 to 1.0 micron range. Fine particles with diameters of 2.5 microns or smaller ($PM_{2.5}$) contribute greatly to the scattering and absorption of light, the sum of which is called light extinction. The significant chemical components in fine aerosols are sulfates, nitrates, organic carbon, soot (light-absorbing carbon), and soil dust.

A wide variety of pollutants may result from daily activities that include driving cars, generating electricity, and producing consumer goods. Depending on location, time of year, and atmospheric conditions, these pollutants can significantly reduce visibility.

Once pollutants enter the atmosphere, their fate is largely determined by meteorological conditions, especially winds, relative humidity, and solar radiation. According to the U.S. Environmental Protection Agency (EPA) (1995), most visibility impairment results from the transport by winds of emitted aerosols, often over great distances (typically hundreds of miles). Consequently, visibility impairment is usually a regional problem rather than a local one. Regional haze is caused by the combined effects of emissions from many sources distributed over a large area, rather than from individual plumes caused by a few sources at specific sites. Stable atmospheric conditions produce stagnation areas that inhibit movement of pollutants, sometimes leading to severe haze episodes (Holzworth and Fisher 1979).

Relative humidity is another weather parameter that affects visibility. In a humid atmosphere, sulfate particles combine with water and grow to sizes that make them more efficient light scatterers. Thus, for a given level of pollution, an atmosphere with higher relative humidity will have more haze than one with lower relative humidity (Sisler and others 1993).

Key Findings

1. A definite seasonal pattern exists. The best visibility occurs during the fall, and the worst visibility occurs during the summer. Summer is also the time of highest $PM_{2.5}$ concentrations.
2. The Upper Buffalo Wilderness on the Ozark-St. Francis National Forests has the best visibility of the three Class I wilderness areas on national forests within the Assessment area.
3. Sulfates are the primary aerosols responsible for visibility impairment within the Assessment area.
4. Visibility impairment in the form of regional haze exists within the Assessment area, but the team found that there are not enough data to identify trends.
5. Compliance with the Clean Air Act amendments of 1990 should reduce sulfates and improve visibility.

Data Sources and Methods of Analysis

Scientists and resource managers use several different types of equipment to measure visibility conditions, each of which differs in terms of cost, siting restrictions, ease of operation, and usefulness of data. The most common types of optical visibility-monitoring equipment include the transmissometer and the nephelometer. These tools directly measure the light-extinction coefficient and scattering coefficient, respectively. Scenic monitoring uses interpretation of 35-mm photographic slides. Aerosol monitors measure the particles in the atmosphere that affect visibility. Combinations of these types of equipment are used to describe and define visibility.

Three different parameters are used to express visibility: standard visual range (SVR), light extinction coefficient (B_{ext}), and the deciview (dv). The Forest Service commonly uses the SVR derived from photographs to measure visibility, although this method has a fair amount of uncertainty associated with it because of the subjective nature of estimates from photographs. The SVR, usually expressed in kilometers, is the greatest distance at which an observer can barely see a black

object the size of a mountain viewed against the horizon sky. The higher the SVR value, the better the visibility.

Another common measure of visibility is the B_{ext} , which represents the ability of the atmosphere to absorb and scatter light. As the light-extinction coefficient increases, visibility decreases. Direct relationships exist between concentrations of particles in the air and their contribution to the extinction coefficient. These relationships are often presented in an annual extinction-budget plot showing the percentage of light extinction attributed to each particle type. The extinction budget (discussed further later) is an important method for assessing the causes of visibility impairment.

Neither the SVR nor the B_{ext} has a consistent direct relationship to perceived visual changes caused by uniform haze. Depending on baseline visibility conditions, a specific change in the SVR or the B_{ext} can result in a visual change that is either obvious or imperceptible relative to the total SVR. For example, an improvement of 10 miles (mi) in SVR may be quite perceptible at an eastern location with an annual average visibility of 40 mi, but a 10-mi change in SVR may not be perceptible at a western location with an annual average visibility of 150 mi.

The dv is another commonly used measure of visibility (Pitchford and Malm 1994). The dv is designed to be perceptually linear (similar to the decibel scale for sound), meaning that a change of any given dv should appear to have approximately the same magnitude of visual change on any scene regardless of baseline visibility conditions. (The dv is designed to describe changes in visibility perception across locations with all types of baseline conditions.) A change of 1 dv is about a 10 percent change in the B_{ext} —a small but perceptible change in visibility. The dv value increases as haze increases, so it is known as a haziness index.

The Forest Service has collected visibility data with cameras at the three Class I areas within the Assessment area, and Air Resource Specialists, Inc., of Fort Collins, CO, has analyzed the findings. Fine mass data ($PM_{2.5}$) were collected as part of the IMPROVE network (Sisler and others 1996). These data were then used to determine extinction budgets showing the percentage of each different aerosol pollutant that causes visibility degradation measured in terms of the SVR.

Patterns and Trends

Table 3.1 gives the average annual camera-based SVR in miles and kilometers as well as the haze factor in dv's for the Class I wilderness areas of the Assessment area from 1988 to 1995. Estimates in this table indicate that Upper Buffalo has the best visibility—perhaps because of the remoteness of this wilderness and prevailing precipitation patterns. Caney Creek normally receives more precipitation than Upper Buffalo and Hercules Glade. The resultant greater number of foggy days and higher relative humidity at Caney Creek would account for the reduced visibility. Photographs of the visibility conditions at the three Class I wildernesses can be seen in figures 3.1 to 3.3.

Figures 3.4 and 3.5 represent the average “clear day,” “median day,” and “hazy day” fine particle (PM_{2.5}) budgets at the Upper Buffalo IMPROVE site for the four seasons from 1992 through 1995. The “fine mass budget” pie charts show the actual percentages of the particle components, based on weight. The “extinction budget” pie charts show by what percentage each constituent reduces visibility.

The top half of figure 3.4 shows that during the winter months over this time period, PM_{2.5} concentrations at the Upper Buffalo site averaged 3.5 milligrams per cubic meter ($\mu\text{g m}^{-3}$) on “clear days,” 6.7 $\mu\text{g m}^{-3}$ on “median days,” and 13.5 $\mu\text{g m}^{-3}$ on “hazy days.” On average, the percentage contribution of nitrate to the fine mass budget (28 percent) equaled the sulfate contribution on “clear days” during the winter months. Increases in sulfate concentration percentages from 28 percent (“clear days”) to 40 percent (“hazy days”) were the main cause of visibility reductions during the winter months over this period. The extinction budgets shown in the top half of figure 3.4 indicate that sulfate contributed an average of 18 percent to the reduction of the SVR (average of 113 kilometers (km)) during “clear days” and 33 percent during “hazy days” (SVR average of 38 km). The reduction in the SVR due to Rayleigh scattering (scattering of light by gas molecules, e.g., nitrogen and oxygen molecules) typically becomes less important relative to the effects of increased sulfate concentrations in the atmosphere when comparing “hazy days” to “clear days.”

Table 3.1—Visibility in Class I wilderness areas represented by camera-based estimates of the average annual standard visual range and haze, 1988 to 1995

Class I wilderness	Clearest ^a			Median ^b			Haziest ^c		
	SVR			SVR			SVR		
	<i>mi</i>	<i>km</i>	<i>dv</i>	<i>mi</i>	<i>km</i>	<i>dv</i>	<i>mi</i>	<i>km</i>	<i>dv</i>
Caney Creek, AR	64	102	13.4	29	47	21.2	13	21	29.2
Hercules Glades, MO	78	125	11.4	46	73	16.8	24	39	23.1
Upper Buffalo, AR	86	137	10.5	47	75	16.5	19	30	25.7

SVR = standard visual range; mi = miles; km = kilometers; dv = deciviews.

^a “Clearest” represents the best visibility conditions. Of all the observations, only 10 percent were better and 90 percent were worse than these conditions.

^b “Median” represents median visibility conditions. Of all the observations, 50 percent were better and 50 percent were worse than the median conditions.

^c “Haziest” represents the worst visibility conditions. Of all the observations, 90 percent were better and 10 percent were worse than these conditions.



Caney Creek Wilderness
Visual Range: 68-106 miles

Category: Good
Visibility this good occurs 10-25% of the time.



Caney Creek Wilderness
Visual Range: 28-43 miles

Category: Medium
Visibility at this level occurs 40-60% of the time.



Caney Creek Wilderness
Visual Range: 16-19 miles

Category: Poor
Visibility this poor occurs 10-25% of the time.



Caney Creek Wilderness
Visual Range: < 7 miles

Category: Bad
Visibility this bad occurs less than 1% of the time.

Figure 3.1—Visibility conditions at the Caney Creek Wilderness on the Ouachita National Forest in Arkansas (photos: USDA Forest Service, Ouachita National Forest, Hot Springs, AR).



Hercules Glades Wilderness
Visual Range: 68-118 miles

Category: Good
Visibility this good occurs 10-25% of the time.



Hercules Glades Wilderness
Visual Range: 37-56 miles

Category: Medium
Visibility at this level occurs 40-60% of the time.



Hercules Glades Wilderness
Visual Range: 22-31 miles

Category: Poor
Visibility this poor occurs 10-25% of the time.



Hercules Glades Wilderness
Visual Range: < 16 miles

Category: Bad
Visibility this bad occurs less than 1% of the time.

Figure 3.2—Visibility conditions at the Hercules Glades Wilderness on the Mark Twain National Forest in Missouri (photos: USDA Forest Service, Mark Twain National Forest, Rolla, MO).



Upper Buffalo Wilderness
Visual Range: 93-137 miles

Category: Good
Visibility this good occurs 10-25% of the time.



Upper Buffalo Wilderness
Visual Range: 43-62 miles

Category: Medium
Visibility at this level occurs 40-60% of the time.



Upper Buffalo Wilderness
Visual Range: 25-34 miles

Category: Poor
Visibility this poor occurs 10-25% of the time.



Upper Buffalo Wilderness
Visual Range: < 9 miles

Category: Bad
Visibility this bad occurs less than 1% of the time.

Figure 3.3—Visibility conditions at the Upper Buffalo Wilderness on the Ozark-St. Francis National Forests in Arkansas (photos: USDA Forest Service, Ozark-St. Francis National Forests, Russellville, AR).

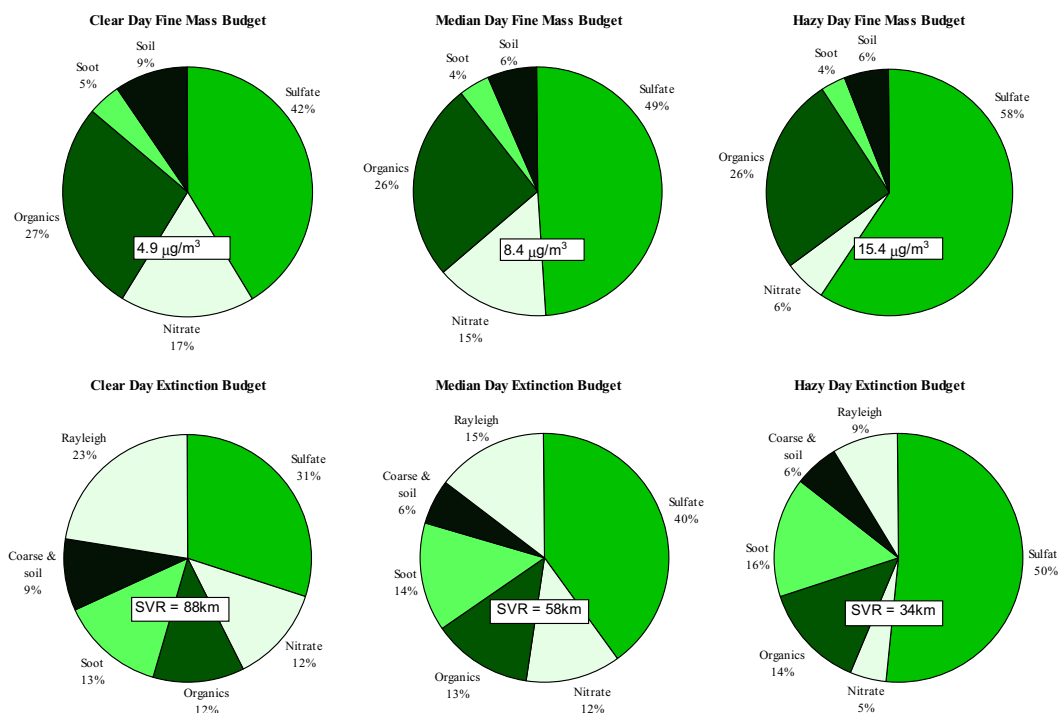
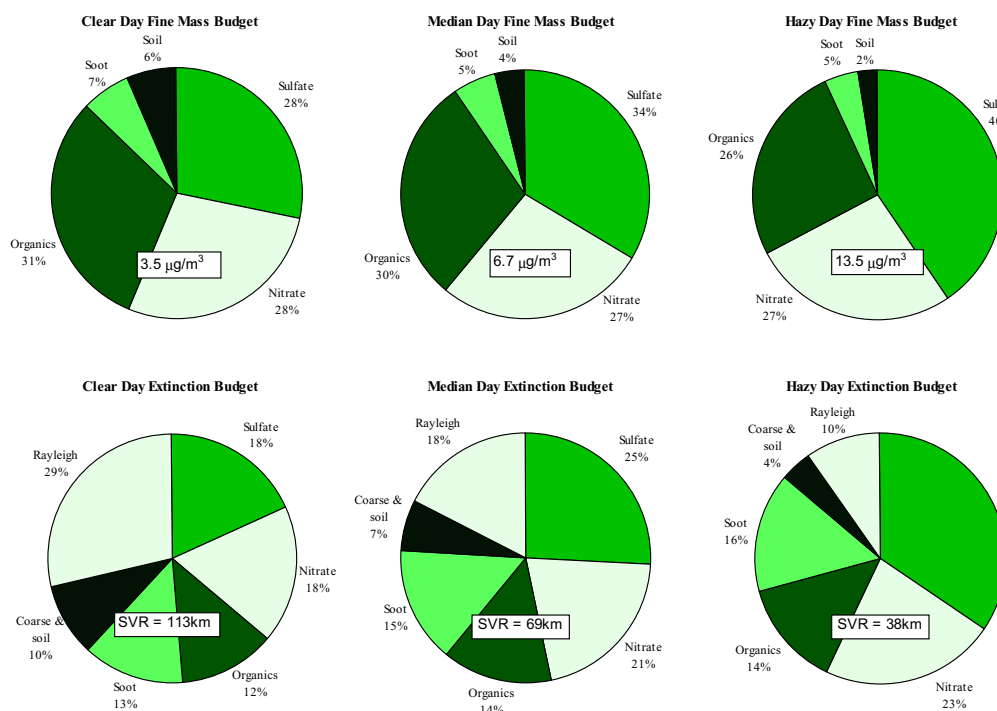


Figure 3.4—The fine particle ($\text{PM}_{2.5}$) budget at the Upper Buffalo Wilderness IMPROVE site for winter (top half) and spring (lower half) from 1992 through 1995. The “fine mass budget” pie charts show the actual percentages of particle components, based on weight. The “extinction budgets” show by what percentage each constituent reduces the standard visual range (SVR).

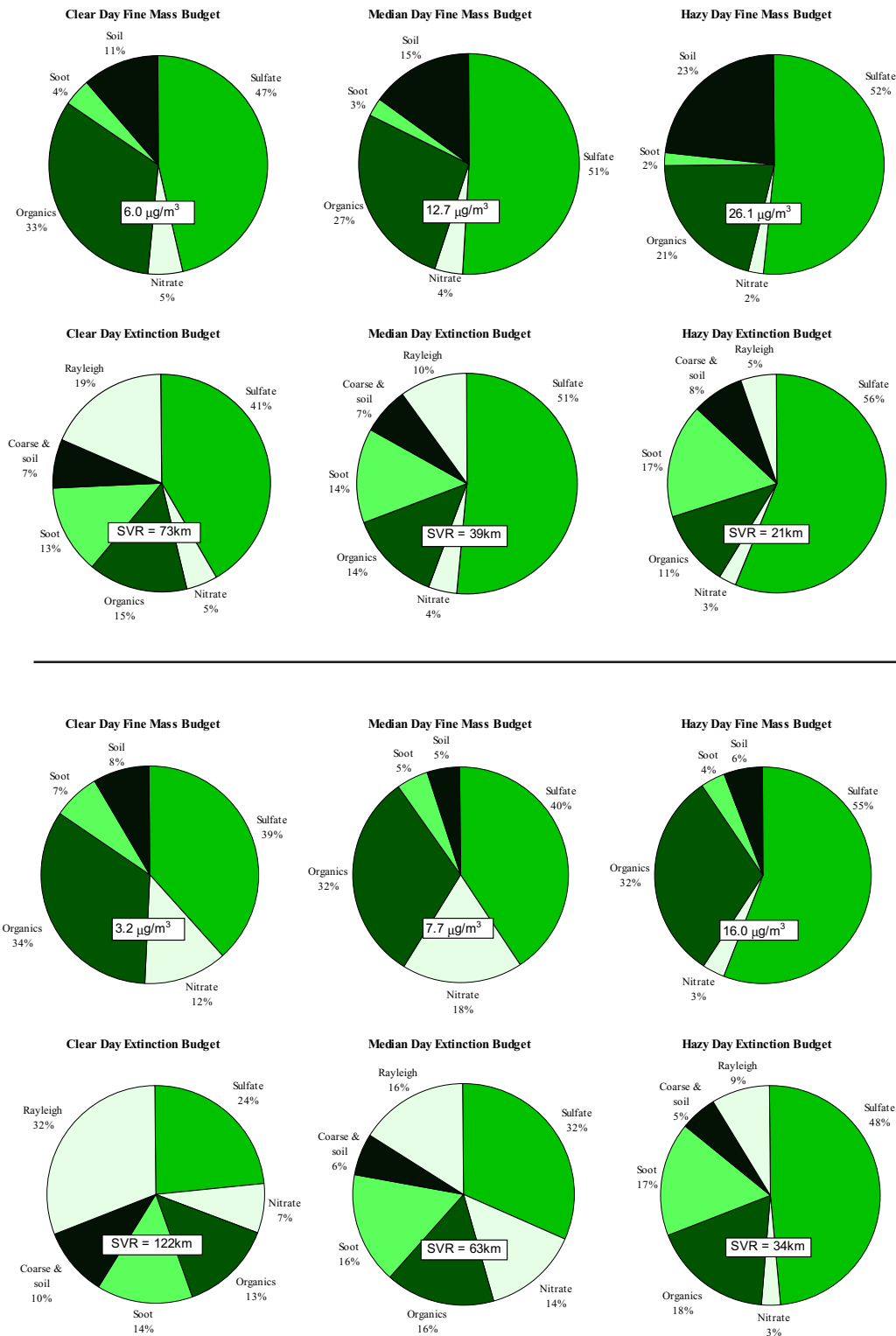


Figure 3.5—The fine particle ($\text{PM}_{2.5}$) budget at the Upper Buffalo Wilderness IMPROVE site for summer (top half) and fall (lower half) from 1992 through 1995. The “fine mass budget” pie charts show the actual percentages of particle components, based on weight. The “extinction budgets” show by what percentage each constituent reduces the standard visual range (SVR).

As average $PM_{2.5}$ concentrations increase from the winter to spring months, visibility typically decreases. The fine mass budgets shown in the lower half of figure 3.4 indicate that average $PM_{2.5}$ concentrations at the Upper Buffalo Wilderness site ranged from $4.9 \mu g m^{-3}$ to $15.4 \mu g m^{-3}$ for “clear” and “hazy” days, respectively, from 1992 through 1995. As in the winter months, increases in sulfate concentrations were responsible for the reductions in the SVR (88 km during “clear days,” 58 km during “median days,” and 34 km during “hazy days”). Sulfate accounted for 42 percent of the $PM_{2.5}$ mass budget on “clear days” and 58 percent of the $PM_{2.5}$ mass budget on “hazy days.” Nitrate, on the other hand, decreased from 17 percent of the $PM_{2.5}$ mass budget on “clear days” to 6 percent on “hazy days.”

The poorest visibility at the Upper Buffalo Wilderness site typically occurs during the summer months, as shown in the top half of figure 3.5. The average SVR on “clear days” from 1992 through 1995 was 73 km and decreased to 21 km during “hazy days.” Changes in the $PM_{2.5}$ mass budget associated with “clear” and “hazy” days included a slight increase in the sulfate percentage (47 to 52 percent), an increase in the soil percentage (11 to 23 percent), and a decrease in the organics percentage (33 to 21 percent). These constituent changes in the budget resulted in average $PM_{2.5}$ concentrations of $6.0 \mu g m^{-3}$ on “clear days” and $26.1 \mu g m^{-3}$ on “hazy days.” Although the contribution of soil particles to the increase in $PM_{2.5}$ concentrations on “hazy days” was significant, the percentage contribution of soil particles to the SVR extinction budget did not change substantially from “clear days” to “hazy days” at the site from 1992 through 1995 (7 to 8 percent). In contrast to the soil particles, the slight increase in the sulfate percentage of the fine mass budget (47 to 52 percent) from “clear” to “hazy” days resulted in a 41 to 56 percent change in the contribution that sulfate made to the SVR extinction budget.

The lower half of figure 3.5 shows the fall fine mass budgets and extinction budgets for the Upper Buffalo Wilderness site from 1992 through 1995. The average $PM_{2.5}$ concentration during fall “clear days” over this period was similar to the average concentrations observed during winter “clear days” ($3.2 \mu g m^{-3}$ vs. $3.5 \mu g m^{-3}$), and average concentrations on fall “median days” ($7.7 \mu g m^{-3}$) and “hazy days” ($16 \mu g m^{-3}$) were similar to the observed springtime concentrations ($8.4 \mu g m^{-3}$ and $15.4 \mu g m^{-3}$,

respectively). The percentages of all the fine mass particle components that make up the fall fine mass budget did not change significantly from “clear days” to “hazy days” over this period, except for the sulfate and nitrate percentages. The nitrate percentage decreased from 12 percent of the total fine mass budget to 3 percent on “clear days” vs. “hazy days,” while the sulfate percentage increased from 39 to 55 percent. This increase in the contribution of sulfate to the total fine mass budget from “clear days” to “hazy days” resulted in a 24 to 48 percent change in the contribution of sulfate to the reduction in the average SVR (122 km on “clear days” and 34 km on “hazy days”).

Implications and Opportunities

To address the “remedying of any existing impairment” portion of the 1977 CAA amendments, the EPA published a “Notice of Proposed [Regional Haze Regulations]” in the July 31, 1997, Federal Register, Vol. 62, No. 147. These regulations proposed (1) that a “reasonable progress target” be set to reduce visibility impairment due to regional haze and (2) that visibility on the best 20 percent of days not be degraded more than 0.1 dv. In addition, on the 20 percent of most impaired days, visibility must be improved at either the rate of 1 dv per 10 years or 1 dv per 15 years (U.S. EPA 1997).

Title IV (Acid Deposition Control) of the CAA amendments of 1990 specifies that sulfur dioxide (SO_2) emissions will be reduced by 10 million tons and nitrogen oxide (NO_x) emissions by 2 million tons from 1980 emission levels (U.S. EPA 1996). When these reductions are fully implemented by the year 2000, visibility should be improved. As figures 3.4 and 3.5 show, sulfates are the major factor in visibility reduction, especially during the summer when visibility is poorest. Newly proposed $PM_{2.5}$ and ozone regulations, while targeted to improve human health, should have the added benefit of improving visibility through anticipated reductions in atmospheric sulfate concentrations.

Chapter 4: Ground-Level Ozone

Question 4: What impact does ground-level ozone have on forests?

Ozone, a naturally occurring chemical in the upper atmosphere and at ground level, is potentially the most significant pollutant affecting forests in North America (Barnard and others 1991). Hourly average concentration levels of ozone near the ground are usually less than 0.04 parts per million (ppm) in undeveloped areas of the world with little anthropogenic pollution (Lefohn and others 1990). Hourly average concentrations above 0.05 ppm are frequently recorded at monitoring stations in the Eastern United States (Lefohn and Jones 1986).

Ozone is formed by the reaction of nitrogen oxides with volatile organic compounds on hot sunny days (NRC 1991). Chameides and Cowling (1995) suggest that ground-level ozone formation is likely to be limited in the Southern United States by the amount of nitrogen oxides in the atmosphere. High amounts of nitrogen oxides are emitted in counties with large cities within and outside of the Ozark-Ouachita Highlands (fig. 1.6). The release of nitrogen oxides, in combination with natural and anthropogenic sources of volatile organic compounds, has the potential to result in ozone concentrations that can damage or injure forest vegetation.

Ozone enters a leaf through openings called stomata. Several factors affect the uptake of ozone by a plant, but primarily, a plant's genetic makeup influences its response. Plant species vary in sensitivity to ozone; even within a species, variations can occur. For instance, during field surveys, researchers have found one plant with severe ozone symptoms growing adjacent to an individual of the same species with no ozone symptoms. In an example outside the Assessment area, a portion of the most ozone-sensitive eastern white pines appears to have been removed from the population due to ozone exposures (U.S. EPA 1986). Other factors, such as light, temperature, relative humidity, soil nutrients, and soil moisture also influence the uptake of ozone. The U.S.

Environmental Protection Agency (EPA) (1986) has presented evidence that indicates that drought stress may reduce the impact of ozone on plants (because the closed stomata prevent ozone entry into the leaves). The vegetation could suffer growth losses, of course, due to the lack of moisture.

Monitored concentrations in the atmosphere are recorded as hourly average values in parts per million in the data base. These concentrations represent "exposure," defined as the amount of ozone that contacts the outside of the leaf. As used here, the term "dose" is the amount of ozone that actually enters the leaf. Estimates of dose are difficult to make without detailed modeling of the relationship between exposure and dose. Exposure is used as a surrogate for dose; researchers and policy-makers use exposures to assess the possible effects of ozone on vegetation.

Ozone inside the leaf is either destroyed by biochemical processes or the ozone kills the cells found just below the upper leaf surface and between the veins of the leaf. Cells that are killed lose their green pigmentation and usually turn reddish or black in a process called stippling. The symptoms of ozone injury cannot be observed until a large number of cells are dead. People who conduct field surveys have a checklist of characteristics to identify plants with ozone symptoms. The visible symptoms (stippling) indicate that the plant has had a physiological response to the ozone dose, resulting in injury. Damage results when the ozone dose was large enough to reduce the intended human use or the value of the plant or ecosystem (Tingey and others 1991).

Several surveys of ozone symptoms have been conducted within and near the Ozark-Ouachita Highlands. Between 1991 and 1995, the incidence of ozone symptoms at the Caney Creek Wilderness and Upper Buffalo Wilderness was low. The percentage of blackberry plants with ozone symptoms was highest in 1991, with 14 percent showing symptoms at Caney Creek and 24 percent at Upper Buffalo. In 1995, there were no ozone symptoms on any of the blackberry plants (Kertz and others 1995).

This chapter will focus on the possible extent and frequency of damage from ozone to trees in forest settings. The Atmospheric Team uses the term “damage” to mean that ozone exposure has likely been sufficient to cause reduced tree growth (Dowsett and others 1992).

Key Findings

1. Using available ozone monitoring data, it appears that ground-level ozone had a minimal impact on forest tree growth between 1990 and 1995.
2. There are few ozone monitors within the Assessment area. Consequently, there could be localized areas where growth losses occurred to trees that are highly sensitive to ozone.
3. Future ozone exposure may be less as Federal, State, and local air pollution control agencies implement strategies to reduce pollution, especially nitrogen oxide (which will, in turn, reduce the formation of ground-level ozone).

Data Sources and Methods of Analysis

Ozone formation is strongly influenced by meteorological conditions and the amounts of ozone precursors present in the atmosphere (NRC 1991). For example, 1988 was a hot and dry year during which large sections of the Eastern United States had high ozone exposures. In comparison, 1989 was cool and moist, and the ozone exposures were low (Lefohn and others 1997). The range in yearly ozone exposures required that more than 1 year be examined to describe the current condition for the study area. Therefore the team selected 1990 through 1995 as the period for analysis.

For this Assessment, data in the EPA’s Aerometric Information Retrieval System (AIRS) data base and from the National Dry Deposition Network program were used. The monitoring sites included those in the States of Arkansas, Illinois, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Oklahoma, Tennessee, and Texas. The monitoring sites selected from these States had 75 percent or greater data capture for each particular year. Numerous statistics were calculated using the 24-hour period over the growing season, defined as the months of

April through October. Initially, many researchers used long-term average concentrations to describe ozone exposures when assessing vegetation effects (Heck and others 1982). The EPA (1989) examined the peer-reviewed literature and concluded that long-term averages are not adequate indicators for relating ozone exposure to plant response. Furthermore, the EPA (1986 and 1992) concluded that greater effects to vegetation occur when the exposures include short-term, high concentrations rather than long-term, low concentrations. The team chose to use the mathematical index W126, as described by Lefohn and Runeckles (1987), to evaluate whether trees within the Assessment area may be suffering from growth losses (damage). All of the available hourly ozone estimates were used to calculate the seasonal W126. Results obtained from the W126 calculations (or any other cumulative exposure index) can have high values, but concentrations equal to or above 0.10 ppm may not occur. Consequently, the Atmospheric Team followed the recommendation of Lefohn and Foley (1992) and included the number of hours greater than or equal to 0.10 ppm in the analysis.

Numerous studies have been conducted to examine the relationship between ozone exposures and tree response. Lefohn and others (1997) reviewed the controlled exposure studies and recommended a technique that divided the landscape into four categories, based on the W126 statistic and the number of hours the ozone concentration was greater than or equal to 0.10 ppm. To accomplish this task, it was necessary to extrapolate the ozone monitoring data beyond the monitoring sites. Extrapolations of the W126 values across the Assessment area were accomplished using a statistical technique described in a report by Lefohn and others (1995). The W126 estimates were made for the center of grid cells of 0.5 degrees latitude by 0.5 degrees longitude across much of the region (fig. 4.1). Estimates were not available for the northern portion of the Assessment area. The add-on software to ArcView® called Spatial Analyst® was used to interpolate the W126 values between the points and for the northern portion of the Assessment area. A spline technique was used for the interpolations to a 6.2-mile (mi) by 6.2-mi grid. Twelve points were used for the spline interpolation, but estimates only were made for the area within the Assessment boundary.

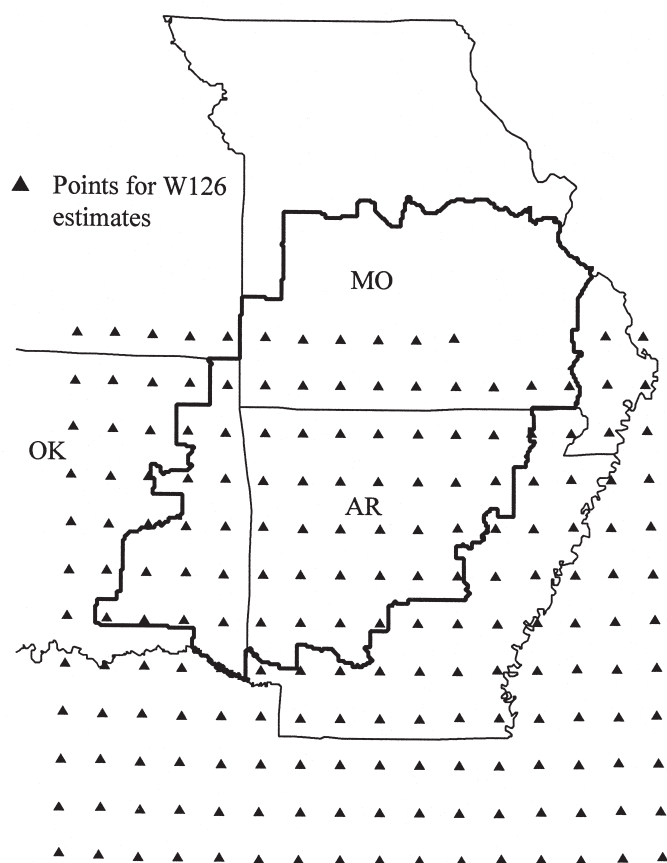


Figure 4.1—Locations of W126 estimates.

The team then categorized the interpolated W126 values (grids) as follows:

- Minimal—Ozone exposure is so low that little or no growth loss is predicted to occur in any species. Ozone symptoms may have been present even though the exposures were low.
- Level 1—Ozone exposure is high enough to cause growth reductions in species considered highly sensitive to ozone, such as black cherry.
- Level 2—Ozone exposure is high enough to cause growth reductions in species with moderate sensitivity to ozone, such as tulip poplar, in addition to those species that are included in Level 1.
- Level 3—Ozone exposure at this level is high enough to cause growth loss in many species—even those normally considered resistant to ozone exposures such as red oak—in addition to those species in Level 1 and Level 2.

The Atmospheric Team used a subjective analysis to classify the amount of area within a tree response category (table 4.1). The criteria listed in table 4.1 required consistency with both the W126 and the number of hours with concentrations greater than or equal to 0.10 ppm. Because the number of hours greater than or equal to 0.10 ppm was not statistically extrapolated across the study area, it was necessary to finish the classification by visually examining the monitored values for the number of hours greater than or equal to 0.10 ppm. Grids that had one or more ozone monitors present were classified using the results from the ozone monitors, but cells that did not have an ozone monitor were classified by examining the pattern from ozone monitors surrounding the cell to be classified. Grids that met the W126 criteria for a particular category and not the number of hours greater than or equal to 0.10 ppm for the same category were assigned the category that matched the number of occurrences greater than or equal to 0.10 ppm.

The experimental studies summarized by Lefohn and others (1997) used plants grown under optimum conditions of adequate soil moisture and nutrients. Before the team applied the criteria in table 4.1, they gathered

Table 4.1—Forest tree response categories based on W126 values and exposure hours required for various levels of forest tree damage

Forest tree response category	W126 values	Exposure hours
	<i>ppm</i>	<i>hours</i>
	<i>hours</i>	<i>≥ 0.10 ppm</i>
Minimal	≥ 0	and ≥ 0
Level 1 (only highly sensitive species affected, e.g., black cherry)	≥ 5.9	and ≥ 6
Level 2 (moderately sensitive species affected, e.g., yellow-poplar)	≥ 23.8	and ≥ 51
Level 3 (resistant species affected, e.g., red oak)	≥ 66.6	and 135

W126 = ozone exposure index; ppm = parts per million; exposure hours = number of hours the hourly average ozone concentrations is ≥ 0.10 ppm.

Source: Lefohn and others (1997).

information on whether the environmental conditions were favorable for ozone to enter the leaf. Of the environmental conditions that need to be considered, soil moisture has been identified as an important variable that influences the uptake of ozone by a plant (U.S. EPA 1986). Showman (1991) and Jackson and others (1992) have observed fewer ozone symptoms on sensitive species during periods of drought than in seasons with adequate rainfall, even though ozone exposures were higher during the drought. Thus, the Atmospheric Team chose the Palmer Hydrologic Index (Palmer 1965) as a surrogate measurement of soil moisture. The index is a monthly value computed for specific climate divisions (regions within a State with similar climatic and hydrologic characteristics). Also, the index indicates the severity of a wet or dry spell. A Palmer Hydrologic Index of less than -2 (minus two) was considered to indicate low soil-moisture conditions, that is, a drought (Briffa and others 1994). The team hypothesized that ozone exposure would not damage the plants during a drought. Values above -2 indicated adequate soil moisture, when ozone could potentially penetrate leaves and damage plants. The average Palmer Hydrologic Index for April through July was calculated for each climate division.

Combining the results from the Palmer Hydrologic Index (fig. 4.2) and ozone exposure (fig. 4.3) provides an indication that (1) soil moisture was sufficient for plants to keep their stomata open enough for ozone to penetrate the leaves and (2) ozone exposures were severe enough to cause growth losses. Areas classified as experiencing a drought (dry) were assigned the growth response category of “minimal” effect from ozone; otherwise the sensitivity category value remained the same after applying the criteria in table 4.1.

Patterns and Trends

The average April to July Palmer Hydrologic Index values from 1990 to 1995 indicate that normal to wet conditions were prevalent over the Assessment area (fig. 4.2 shows the average April to July Palmer Hydrologic Index values for 1990 only). Consequently, the team hypothesized that the stomata were open at times during the growing season, and ozone could have penetrated into the leaves. The results from statistical estimates placed

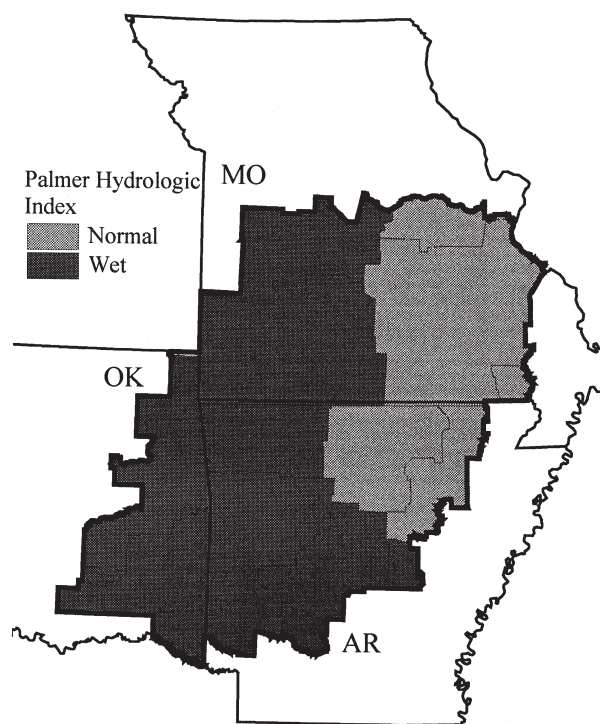


Figure 4.2—Palmer Hydrologic Index results for April through July 1990.

almost all of the Assessment area into W126 values of 5.9 to 23.8 ppm hours (Level 1) for the years 1991 through 1993 (figs. 4.4, 4.5, and 4.6). Whereas, in 1990, 1994, and 1995 (figs. 4.3, 4.7, and 4.8), most of the Assessment area had W126 values between 23.8 and 66.5 ppm hours (Level 2), no areas were classified as having less than 5.9 ppm hours (minimal). Using only the W126 values would indicate that Level 1 and/or Level 2 tree species may have had growth losses for the 6 years. However, hourly average ozone concentrations were seldom greater than or equal to 0.10 between 1990 and 1995.

Most of the ozone monitors within and near the Assessment area indicated less than 6 hours during the growing season when the average hourly concentrations were greater than or equal to 0.10 ppm (figs. 4.3 to 4.8). Therefore, by following the recommendation of Lefohn and Foley (1992) and the procedure of Lefohn and others (1997), the team decided it is likely that ground-level ozone exposures had a minimal impact to forest trees and that no growth losses resulted from ozone exposures. The lack of ozone symptoms reported by Kertz and others

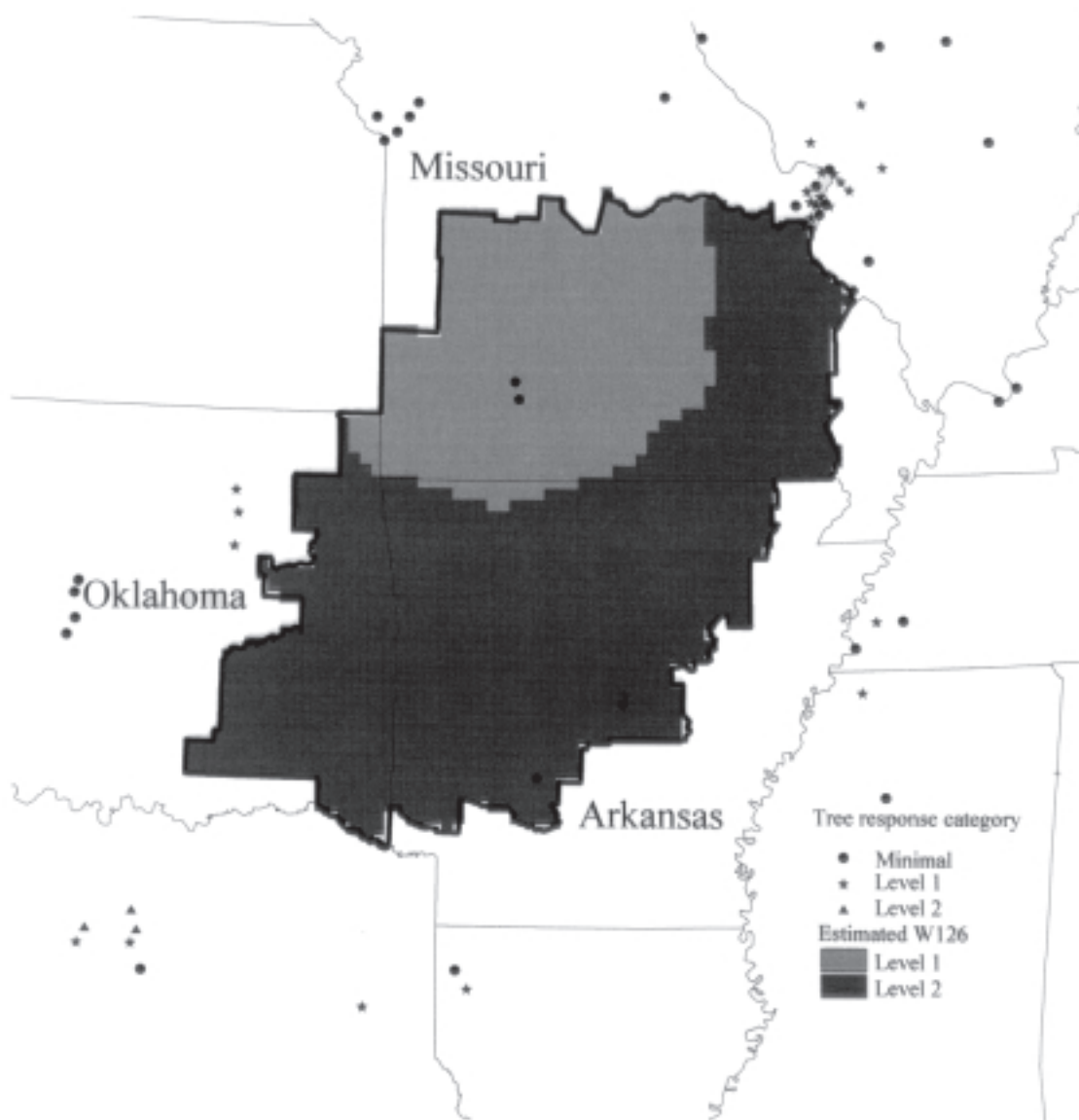


Figure 4.3—Ozone estimates for 1990 showing sites classified according to tree response categories (see table 4.1) and W126 values.

(1995) provides additional evidence that ozone likely had a minimal impact on forest tree growth.

The team believes caution should be used in interpreting these findings since there were less than 10 ozone monitors collecting data within the Assessment area between 1990 and 1995. There could be localized areas within the Ozark-Ouachita Highlands with more than 5 hours of hourly averaged ozone concentrations greater than or equal to 0.10 ppm. If such events did occur, the potential for growth losses to the most sensitive species

(Level 1) may have been realized in localized areas, possibly near St. Louis, MO, and Tulsa, OK. Conversely, it is important to note that the W126 exposure index values for this study were accumulated for the growing season—April through October. Most of the experimental data used in this Assessment were collected for 3 to 4 months (Lefohn and others 1997). Thus, using a 7-month period to accumulate the W126 value may overestimate the likelihood of predicted growth losses.

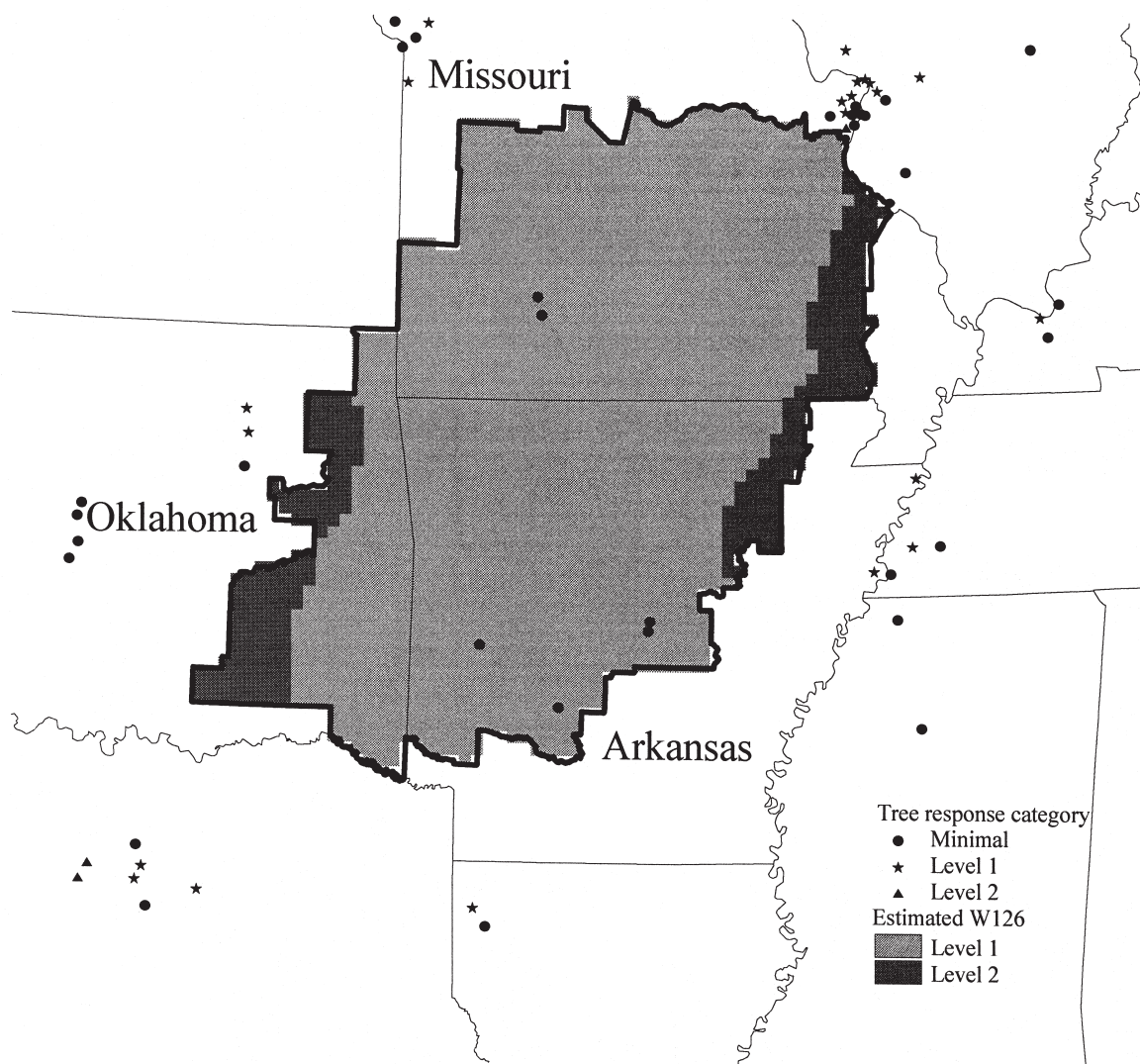


Figure 4.4—Ozone estimates for 1991 showing sites classified according to tree response categories (see table 4.1) and W126 values.

Implications and Opportunities

Current emission strategies implemented by local, State, and Federal air pollution agencies may reduce ozone exposures in rural forests in the future. For example, there could be a lowering of ozone exposures in the Ozark-Ouachita Highlands as ozone nonattainment areas outside the study area (such as Dallas) implement control strategies that bring the urban area back into compliance with Federal law. Furthermore, the revision of the National Ambient Air Quality Secondary (NAAQS)

standard to an 8-hour average of .085 ppm is likely to benefit forests. To lessen the risk of tree growth loss, air pollution control agencies will have to implement emission reduction strategies in areas that violate the new primary standard and decrease the number of hours of average ozone concentrations greater than or equal to 0.10 ppm.

Ozone exposures in the study area result from the chemical reaction of nitrogen oxides and volatile organic compounds. The volatile organic compounds are known to be so abundant (figs. 1.8 and 1.10) that it appears nitrogen oxides may be the limiting factor in ozone

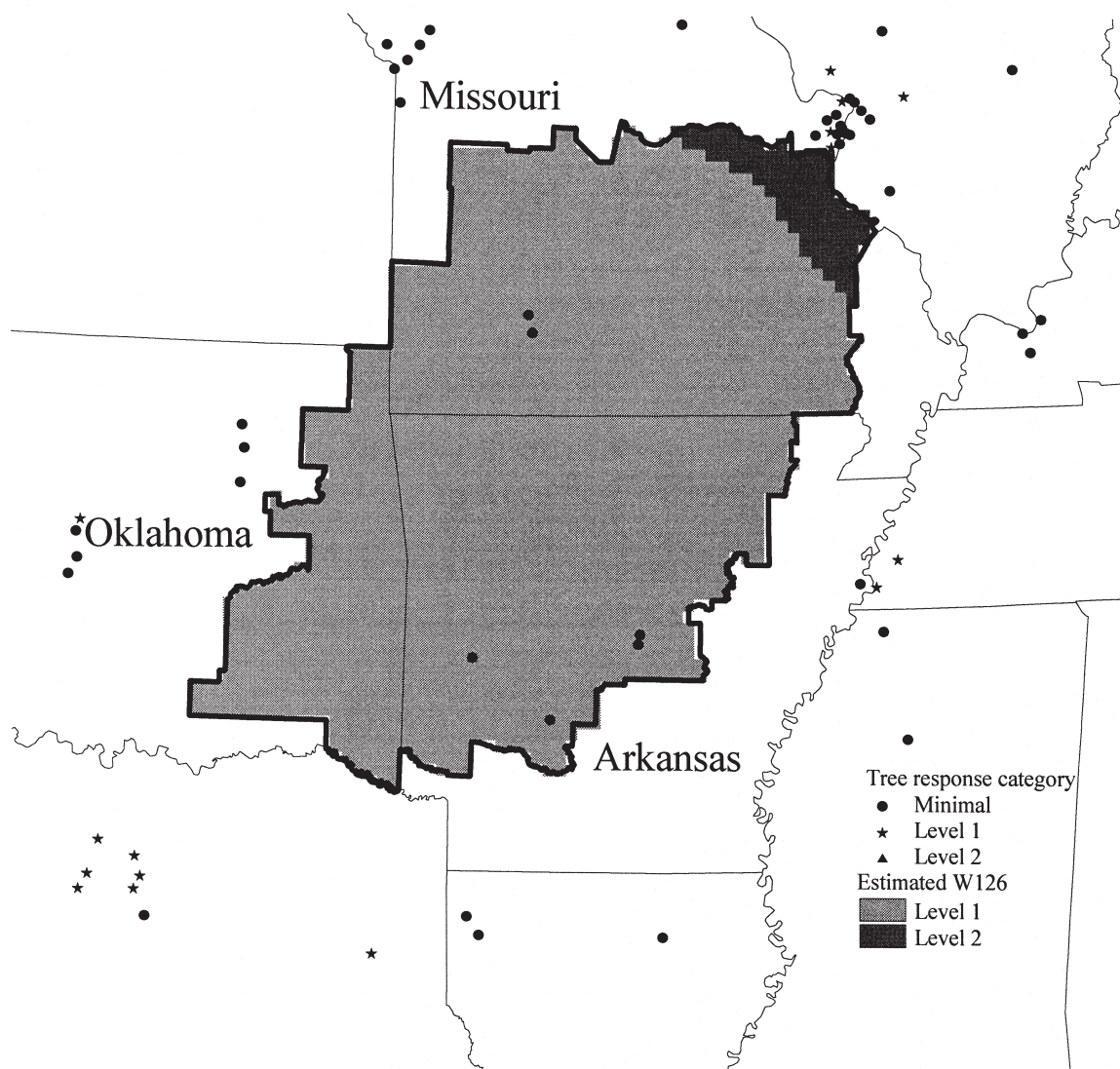


Figure 4.5—Ozone estimates for 1992 showing sites classified according to tree response categories (see table 4.1) and W126 values.

formation (Chameides and Cowling 1995). Implementation of and compliance with the Clean Air Act Amendments of 1990 should reduce nitrogen oxide emissions nationally by 2 million tons and may reduce ozone exposures further within the Assessment area. Other strategies that reduce nitrogen oxides may also result in lower ozone exposures for the Ozark-Ouachita Highlands area. Recently, the EPA notified State and local air pollution control agencies in 22 Eastern States that further reduc-

tions in nitrogen oxides are needed for some urban areas to satisfy the NAAQS for ground-level ozone. Of the States included in this analysis, the EPA requested that Illinois, Kentucky, Missouri, and Tennessee reduce between 35 and 43 percent of emissions of nitrogen oxides. Implementation of nitrogen oxide reductions of this magnitude likely will reduce the amount of ground-level ozone in the Assessment area.

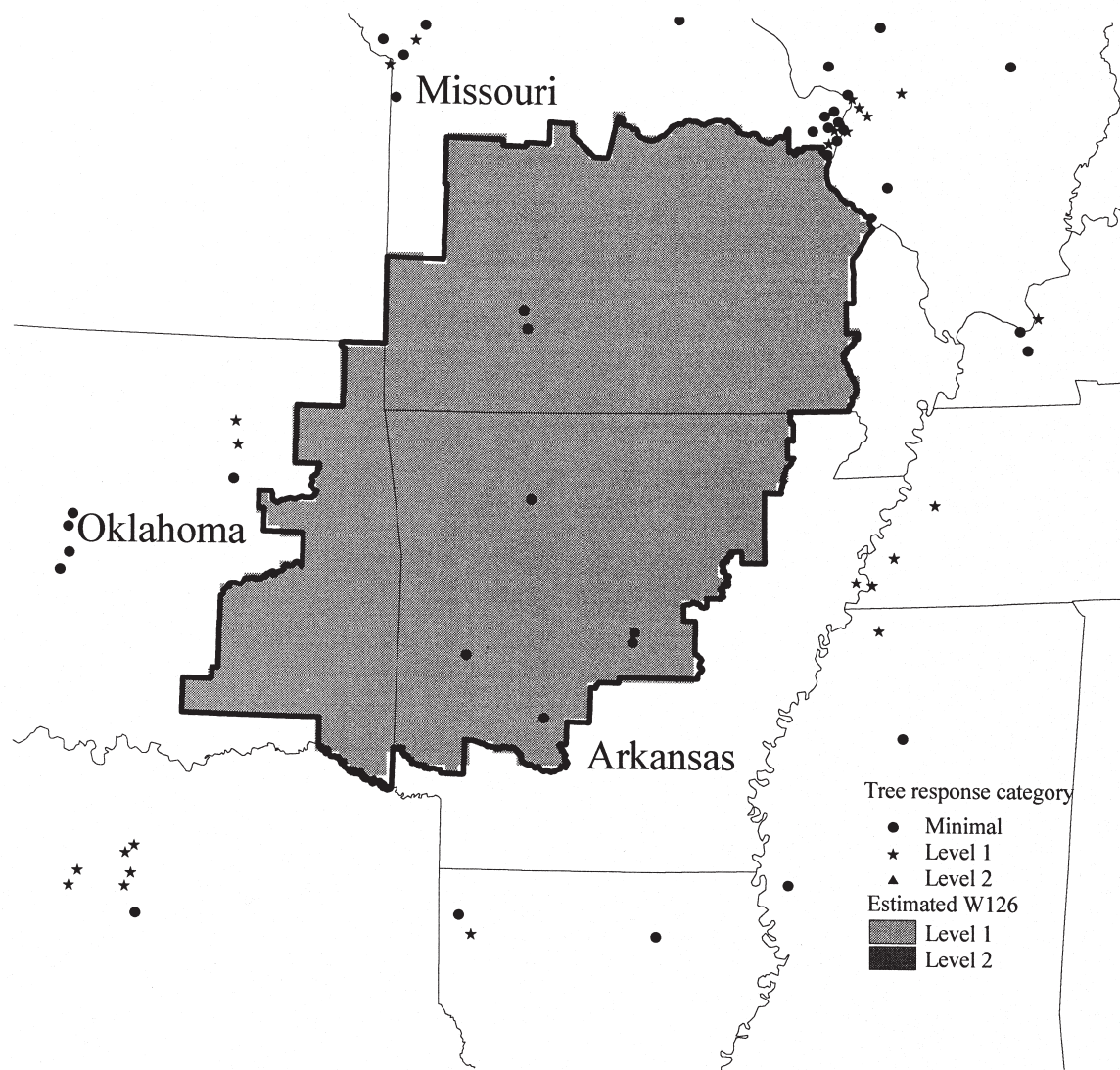


Figure 4.6—Ozone estimates for 1993 showing sites classified according to tree response categories (see table 4.1) and W126 values.

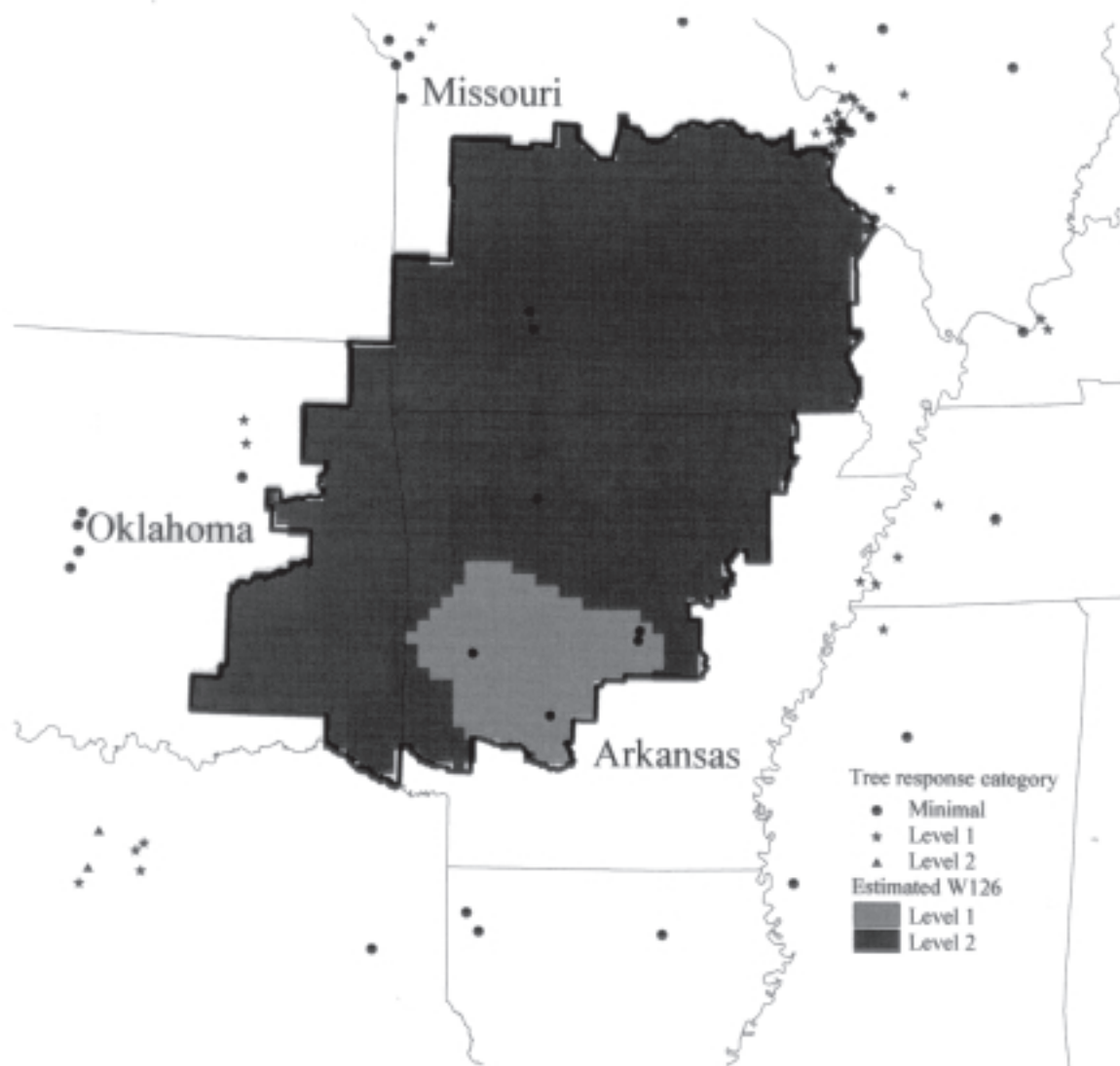


Figure 4.7—Ozone estimates for 1994 showing sites classified according to tree response categories (see table 4.1) and W126 values.

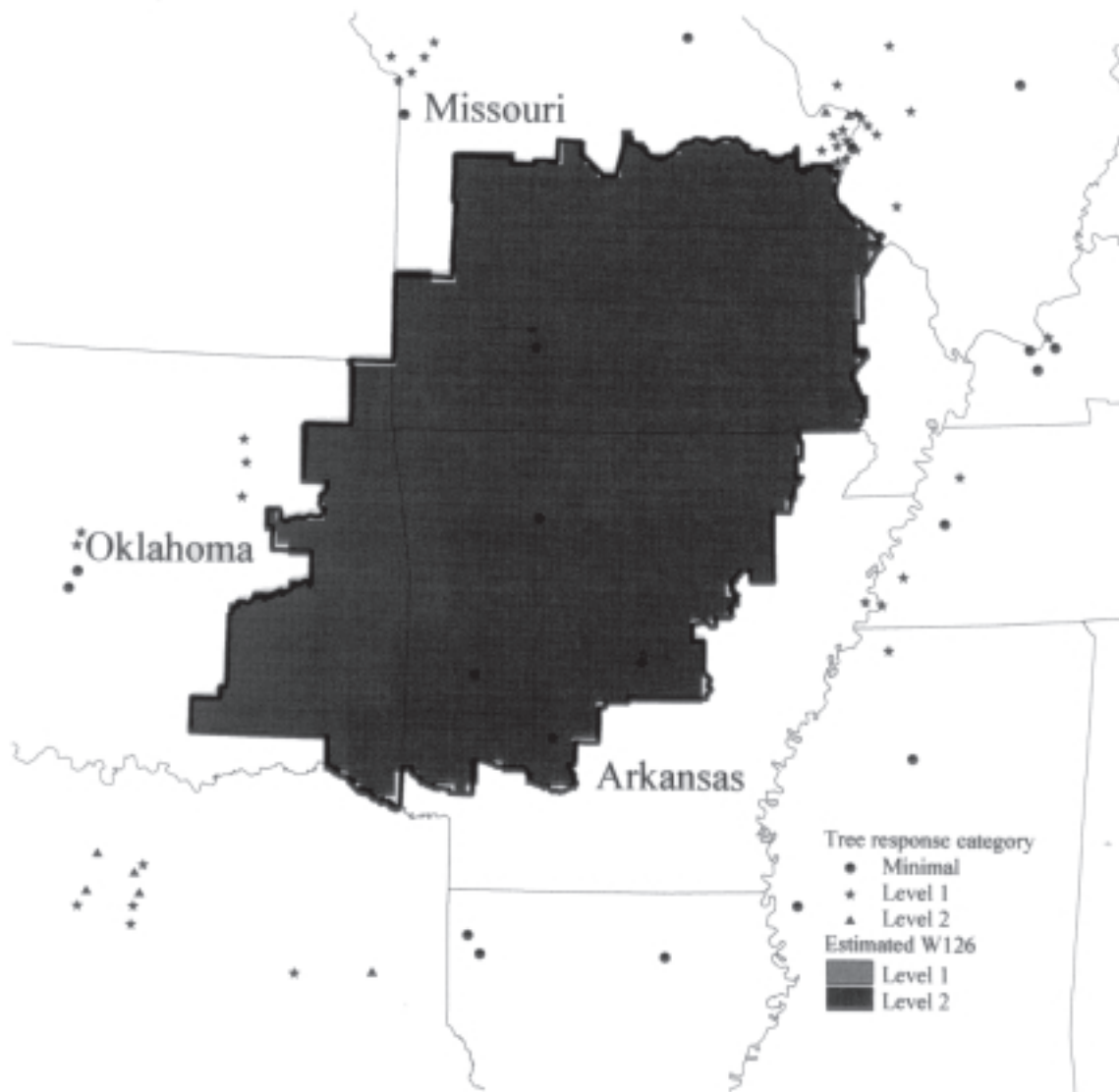


Figure 4.8—Ozone estimates for 1995 showing sites classified according to tree response categories (see table 4.1) and W126 values.

Chapter 5: Acid Deposition

Question 5: To what extent are resources in the Highlands being affected by acid deposition?

Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) present in the atmosphere can react with water, oxygen, and oxidants (such as ozone) to form mild solutions of sulfuric acid and nitric acid (U.S. EPA 1998a). These acidic solutions are often found in rainwater, snow, fog, and other forms of precipitation. When precipitation containing these acidic compounds falls to the earth, the acidic compounds are deposited on the earth's surface (acid deposition or wet deposition), and the precipitation carrying the acidic compounds is referred to as "acid rain." Scientists have discovered that air pollution from the burning of fossil fuels is the major cause of acid rain. Acidic compounds in the atmosphere and the deposition of acidic compounds on the earth's surface can disrupt forest and aquatic ecosystem functions, impair visibility, and create human health problems.

Chapter 1 provides a regional perspective on sources and amounts of nitrogen (fig. 1.6) and sulfur compounds (fig. 1.12) emitted into the atmosphere. It is worth restating that 28 percent of nitrogen oxide (NO_x) emissions in the Assessment area and nearby are from industrial fuel combustion sources, 22 percent are from vehicles (internal combustion engines), and 20 percent are from electric utilities (fig. 1.5). As figure 1.11 shows, sulfur dioxide (SO_2) is primarily produced from electric power generation (72 percent), with all other industry sources producing 15 percent (U.S. EPA 1996).

Since the mid- to late 1970's, emissions of SO_2 and NO_x have decreased and leveled off, respectively, in contrast to the upward trends in emissions of these gases experienced from the early 1950's to the mid-1970's (fig. 1.17). Vehicle miles traveled have doubled since 1970, but

exhaust emissions have only slightly increased (U.S. EPA 1996) because of better fuel economy and more efficient engines. Since 1996, this same strategy has been applied to selected nonroad categories (e.g., small engines such as lawn mowers and outboard motors). The Environmental Protection Agency (EPA) (1996) expects significant emission reductions after the year 2000. Sulfur emissions have also been reduced per unit of production. From 1970 to 1995, SO_2 emissions from electric utilities decreased about 31 percent (U.S. EPA 1996). Implementation of the Clean Air Act amendments of 1990 should reduce SO_2 emissions by 10 million tons and NO_x by 2 million tons by the year 2000 (U.S. EPA 1996).

The impact of acid deposition on forest and aquatic ecosystems has been the subject of much research and debate. The 1980 to 1990 National Acid Precipitation Assessment Program (NAPAP) provided indepth research on these impacts (see Baker and others 1991). As NAPAP and others have reported, the potential harmful effects of acidic deposition include: (1) leaching of nutrients from plant foliage and the soil by hydrogen, sulfate, or nitrate ions (Lee and Webber 1982); (2) alteration of beneficial micro-organisms in the forest floor and upper soil horizons, including damage to symbiotic nitrogen-fixing organisms (Francis 1982); (3) acid-induced mobility and toxicity of aluminum in the soil solution leading to toxic levels of aluminum in streamflow and water bodies (Steiner and others 1980; Ulrich and others 1980; Johnson and others 1981); (4) increased susceptibility of trees and plants to environmental stresses, including drought (Johnson and others 1981; Lee and Webber 1982); (5) delayed frost hardiness leading to vegetation damage (DeHayes 1992); and (6) acidification of aquatic ecosystems (Herlihy and others 1996). Impacts may thus affect entire ecosystems including vegetation, soil, and the receiving watercourse.

Key Findings

1. Atmospheric wet acid loadings are less than the loadings observed in the Southern Appalachian region. Nitrate and sulfate loadings are expected to decrease in the future based on expected decreases in emissions of sulfur dioxide and nitrogen oxides (see Chapter 1).
2. Most surface waters within the Assessment area do not appear to be adversely impacted by the previous and present rate of acid deposition.
3. The low acid neutralizing capacity headwater areas of the Ouachita Mountains make them most at risk while the limestone areas of the Ozark Plateau are least at risk.

Data Sources and Methods of Analysis

Because nitrate and sulfate depositions over a region are related to precipitation patterns, it was necessary to assess the spatial variations in precipitation over the Assessment area at a sufficient resolution to account for major elevation changes. The deposition model of Lynch and others (1997), used in this Assessment for generating nitrate and sulfate deposition maps, incorporates precipitation patterns that account for the changes in topographic variations observed in the Assessment area. The coordinates, elevations, and monthly precipitation records from the National Oceanic and Atmospheric Administration's (NOAA) precipitation monitoring sites in the States within and adjacent to the Assessment area constitute the precipitation-volume data set used to develop the deposition model. Lynch and others (1997) obtained precipitation concentration data for sulfates and nitrates from weekly rainfall samples collected at monitoring sites within and adjacent to the Assessment area.

The deposition model uses a statistical method that includes: (1) the precipitation observed at monitoring sites, (2) elevation, and (3) a set of variables representing both slope and aspect. The derived regression equations from each 0.1-degree block are then applied to corresponding digital elevation data to produce a grid of precipitation estimates. The current model compares the predicted and observed quarterly and annual precipitation volumes at approximately 1,500 validation sites scattered over the

Assessment area. The average annual estimation error is consistently near 3.0 inches (in.) for each year from 1991 through 1993 (Lynch and others 1997).

The NOAA data set comprises the only precipitation values that cover the Assessment area at a site density sufficient for deposition modeling. A major limitation on the accuracy of the model's precipitation calculations is the imprecise coordinates of the NOAA precipitation sites. NOAA coordinates for the location of a rain gauge are reported at a resolution no finer than 1 minute of a degree of latitude or longitude. This level of uncertainty impedes the modeling of localized—but important—geographic influences on precipitation. The modifications that Lynch and others (1997) made to the model overcame the imprecision of the coordinates and estimated more precise coordinates of each NOAA precipitation monitoring station.

Because precipitation varies year to year, the amount of deposition also varies. Deposition rates, therefore, are modeled values, not measured values; they should be considered relative rather than absolute values and used with caution. Actual values determined at the site of concern will be needed to document any influence on the local ecosystem.

Patterns and Trends

Figures 5.1 and 5.2 indicate that the southwestern part of the Assessment area has the highest sulfate and nitrate deposition. Figure 5.2 shows that sulfate deposition exceeds 20 pounds per acre (lbs/ac) in the high elevation and high precipitation areas of the southwest portion of the Ouachita range. An EPA finding suggests this pattern could be a result of sulfur dioxide emissions from coal-burning industries in Louisiana and Texas (OK WRB 1990). The other area receiving high sulfates but not high nitrate deposition is the northeastern portion of the Assessment area, including the Potosi-Fredericktown District and the eastern half of the Salem District of the Mark Twain National Forest.

Figure 5.3 shows the average modeled sulfate and nitrate deposition within the Assessment area from 1983 to 1995. Compared to the Southern Appalachians, the annual sulfate deposition in the Ozark-Ouachita Highlands is moderate—15 lbs/ac in the Highlands compared to 20 to 25 lbs/ac for the Southern Appalachians. The



Figure 5.1—The period average for nitrate deposition (lbs/ac) in the Assessment area from 1983 through 1995 (Lynch and others 1997).

average annual nitrate deposition in the Assessment area is 10 lbs/ac compared to 15 to 20 lbs/ac in the Southern Appalachians (SAMAB 1996).

During the NAPAP era (1980 to 1990), there was an effort to look for evidence that acidic deposition was affecting surface waters within the Assessment area. Between 1984 and 1986, the EPA conducted one of the largest limnological reconnaissance projects ever undertaken—the National Surface Water Survey (NSWS)—the results of which are available from the EPA. The NAPAP and NSWS used the acid neutralizing capacity (ANC) to rate streams and lakes. This survey found that a relatively high percentage of streams with ANC equal to or greater than 200 existed in the interior Southeast region, which includes the Assessment area, while no lakes or streams in this region had ANC values less than

or equal to zero (Baker and others 1991). However, this same report indicated that the Ozark-Ouachita area had 19 percent of the streams with ANC greater than zero and less than or equal to 50 (Baker and others 1991). These poorly buffered systems can be considered at risk for acidification.

Within the Assessment area, the headwater sections of the Ouachita Mountains in Arkansas contain very little limestone bedrock, while the Ozark Plateau area in Missouri contains large areas of limestone and karst topography (irregular limestone with sinks, underground streams, and caverns). These geological differences suggest that the Ouachita Mountain headwaters are likely to be more at risk for acidification than streams in the Ozark Plateau.

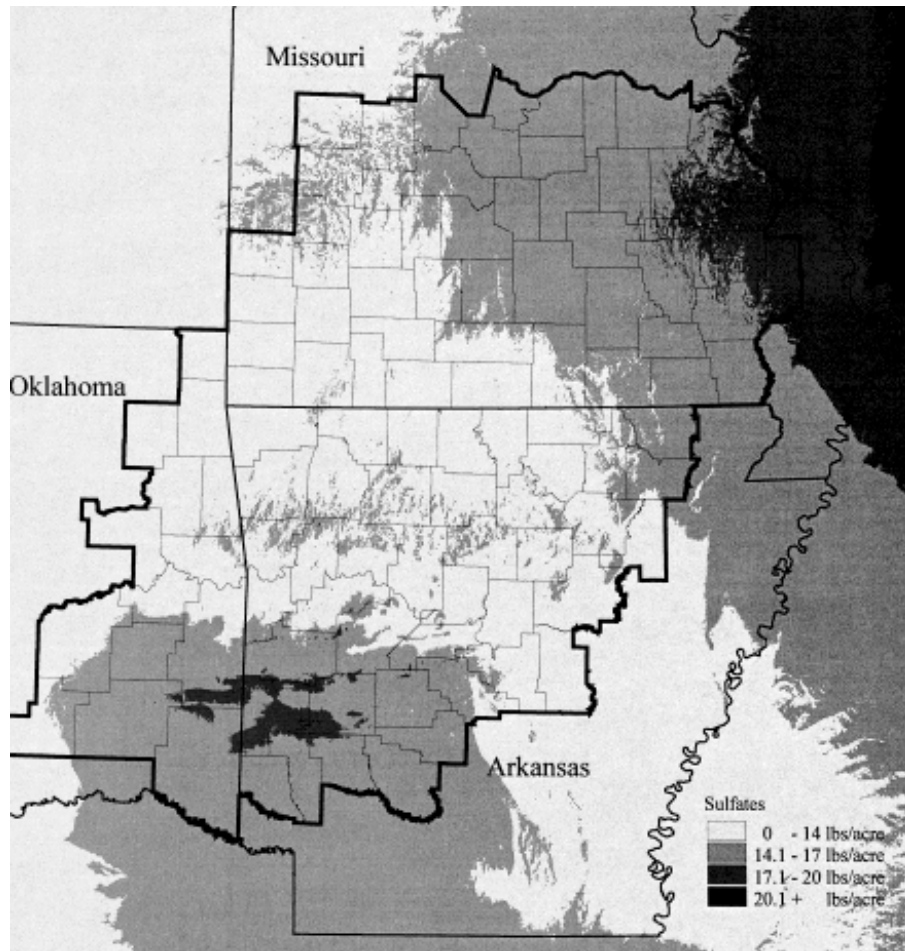


Figure 5.2 The period average for sulfate deposition (lbs/ac) in the Assessment area from 1983 through 1995 (Lynch and others 1997).

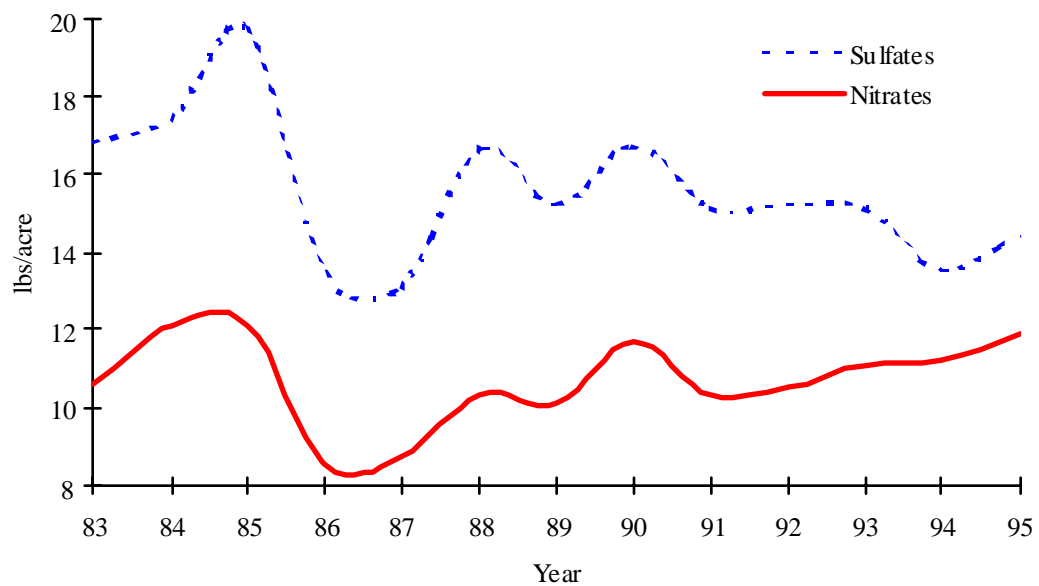


Figure 5.3 Variation in modeled mean sulfate and nitrate deposition within the Assessment area from 1983 through 1995 (Lynch and others 1997).

Another test of acidification is the amount of nitrates and sulfates moving through a system. The consensus of NAPAP is that the streams in the Ozark-Ouachita Highlands are at equilibrium for sulfates and that 99 percent of the nitrates are being retained. Sulfate enrichment is occurring in some waters in the Ozark-Ouachita Highlands (Baker and others 1991).

Nix and Thornton (1987) confirmed the overall NAPAP and NSWS assessment that the higher elevation streams in the Ouachitas are vulnerable to acid deposition. Their major findings were that: (1) during storm events, ionic aluminum is released into surface waters; (2) 90 percent of nitrogen is being retained; (3) sulfates are near equilibrium; and (4) base cations are being exported at twice the rate of precipitation input. They concluded that headwater streams that have low ANC are potentially at risk with respect to acidic deposition.

Precipitation patterns strongly influence acid deposition. As explained in the “Data Sources and Methods” section of this chapter, elevation changes can impact precipitation amounts. The Ouachita Mountains in the southwestern part of the Assessment area can produce orographic lifting (the lifting of air when it flows over higher elevation terrain) of moist air moving northward from the Gulf of Mexico across the Gulf Coastal Plain. The Atmospheric Team expects this area will receive the greatest amount of deposition. Kress and others (1988) found that an average 400-foot increase in elevation from the Gulf Coastal Plain to the Ouachita Mountains in southeastern Oklahoma resulted in a 12-percent increase in average annual precipitation (60.2 to 67.6 in. in 1984 to 1985). They also found the average pH decreased with increased elevation of the station (4.67 at the Coastal Plain to 4.53 at the Ouachita Mountains). Total nitrate deposition increased from 3.2 to 3.5 lbs/ac, and total sulfate deposition increased from 28.3 to 32.7 lbs/ac as elevation increased.

Implications and Opportunities

Acid deposition can pose a threat to forest and aquatic ecosystems—especially on poorly buffered, higher elevation watersheds. Acid deposition patterns in the Assessment area as a result of sulfate and nitrate in the atmosphere are affected by the emissions of SO₂ and NO_x and the patterns of precipitation over the region. As noted in Chapter 1, emissions of SO₂ from electrical utilities in the Assessment area are expected to decrease as the Clean Air Act Amendments of 1990 are fully implemented. Furthermore, the emissions of nitrogen oxides from fuel combustion at industrial sources in the Assessment area will likely be reduced in response to current efforts by the EPA. Future reductions in the emissions of sulfur dioxide and nitrogen oxides should lead to reduced atmospheric sulfate and nitrate concentrations, thereby reducing the potential for acid deposition episodes. However, future changes in precipitation patterns as a result of changes in regional climate and climate variability may also impact the amount of acid deposition over the Assessment area.

A comprehensive assessment of how acid deposition patterns might change over the Assessment area as a result of changing emissions of SO₂ and NO_x and a changing climate (including precipitation patterns) will require the use of coupled, high-resolution atmospheric mesoscale and chemistry models that can generate plausible scenarios of acid deposition, e.g., the U.S. EPA (1998b) Regional Acid Deposition Model. The development of these future scenarios of acid deposition must take into account the complex atmospheric dynamics associated with the emission, transport, and diffusion of the chemical species involved in the formation of acid rain; the dynamics of cloud formation and precipitation occurrence over the region; surface-atmosphere interactions that influence the hydrologic cycle in the region; and the overriding chemical reactions that lead to the formation of sulfuric and nitric acid in the atmosphere. The acid deposition scenarios generated by coupled atmospheric mesoscale and chemistry models can provide vital information to natural resource managers as they develop management strategies for specific watersheds in the Assessment area known to be sensitive to potential acid deposition events.

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Glossary of Terms

acid deposition: rain, snow, or particulate matter containing high concentrations of sulfuric acid, nitric acid, or hydrochloric acid, usually produced by atmospheric transformation of the by-products of fossil fuel combustion. Precipitation with a pH lower than 5.0 is generally considered to be acidic.

anthropogenic gases: chemical gases released into the atmosphere from human activities such as electrical generation, vehicle operation, and manufacturing.

aerosol: a suspension of colloidal particles in a gas.

Class I areas: those areas defined by the Clean Air Act amendments of 1977 as having “special protection” from effects of air pollution because of their “air-quality related values (AQRV’s)” (i.e., water quality, native vegetation, ecosystem integrity, and visibility). Class I wilderness areas are wildernesses larger than 5,000 acres and national parks larger than 6,000 acres that were in existence on or before August 7, 1977.

Criteria Pollutants: pollutants for which National Ambient Air Quality Standards have been implemented to protect human health and welfare. They include: particulate matter, sulfur oxides, nitrogen oxides, carbon monoxide, ozone, and lead.

deciview (dv): the metric unit based on light extinction used for an atmospheric haze index, such that uniform changes in haziness correspond to the same metric increment across the entire range from pristine to highly impaired haze conditions. Deciview values are calculated by multiplying by 10 the natural logarithm of one tenth of the atmospheric light extinction coefficient expressed in units of inverse megameters. As used in this report, it is also a visibility index designed to describe changes in visibility perception across locations with all types of baseline conditions.

dose: the amount of ozone that enters a leaf.

emissions: the amount of a specific pollutant released into the atmosphere.

exposure: the amount of ozone that is found in the ground-level atmosphere or that contacts the outside of the leaf.

fine mass particle: particle with a diameter equal to or smaller than 2.5 microns. Fine particles are responsible for most atmospheric particle-induced light extinction.

fugitive dust: dust generated from geologic wind erosion, agricultural tilling, mining, construction, paved and improved roads, and fugitive process sources (e.g., dust, leaks, uncontrolled vents) at process sites. Fugitive dust is the greatest emission source (71 percent) of PM₁₀ from within and outside the Assessment area.

fugitive emissions: air pollution from an unducted source, i.e., not emanating from an exhaust pipe or stack. Roadway dust and emissions from refinery valves are examples.

fugitive process sources: an EPA category used to discuss PM₁₀. Some fugitive process sources are leaks and uncontrolled vents. Fugitive dust is also generated from geologic wind erosion, agricultural tilling, mining, construction, paved and improved roads, wildlife, prescribed fires, and wildfires.

hygroscopic: having the ability to attract water.

microgram: 0.000001 gram.

micron: 0.000001 meter.

National Ambient Air Quality Standards (NAAQS): air quality standards established and maintained by the Environmental Protection Agency under the authority of the Clean Air Act. The standards are intended to protect human health and welfare.

National Acid Precipitation Assessment Program (NAPAP): the 10-year (1980 to 1990) interagency research program designed to investigate acid deposition and its effects nationwide. The products of this program are the series of State of Science and Technology documents that summarize what is known about the severity of acid deposition and the resources it affects.

nitric oxide: a gas formed under high temperature and/or high pressure combustion in furnaces and internal combustion engines. Nitric oxide is converted to nitrogen dioxide in the presence of oxygen.

nitrogen oxides: a designation of all oxides of nitrogen that includes nitrogen dioxide, nitric oxide, and nitrous oxide, all of which are precursors of atmospheric ozone or nitrogen deposition.

ozone: an atmospheric gas for which a standard is maintained within the NAAQS. This report deals with ozone concentrations near the earth’s surface that may cause injury to plants and animals.

ozone damage: in the context of this report, ozone exposure that is large enough to cause a growth loss in a species known to be sensitive to ozone.

ozone injury: a physiological response to ozone that has entered into a plant's leaf.

ozone symptoms: a discoloration, called stippling, of the upper leaf surface of a plant species known to be sensitive to ozone exposures under controlled conditions. The ozone symptoms are used during field surveys to identify species that are likely to exhibit a physiological response to ozone exposures.

particulate matter: any substance, except pure water, that exists as a liquid or solid in the atmosphere under normal conditions and is of microscopic or submicroscopic size but larger than molecular dimensions (e.g., dust and smoke). Standards for particulate matter are maintained within the NAAQS.

parts per million (ppm): a unit of measure used for describing ozone exposure.

pH: the negative logarithm of hydrogen ion activity. The pH scale goes from 1 (most acidic) to 14 (most alkaline). The difference of 1 pH unit indicates a tenfold change in hydrogen ion activity.

point source: includes any identifiable conveyance from which pollutants might enter the air of the United States (e.g., smokestack).

Pollution Exposure Index (PEI): a statistical modeling technique used to assess where pollution exposures may be the greatest.

prescribed burn or fire: a fire burning within the parameters of a written statement that defines objectives to be attained and conditions under which the fire will be allowed to burn (e.g., wind direction and speed, fuel moisture content).

Rayleigh extinction: the natural reduction in visibility caused by nitrogen and oxygen molecules (clean air).

reasonable progress target (visibility): an improvement in the average of the 20 percent most impaired days each year, equivalent to an improvement (decrease) of (Option A) 1.0 deciview (dv) per 10 years or (Option B) 1.0 dv per 15 years and no degradation (less than 0.1 dv increase) in the average of the 20 percent least impaired days each year.

receptors: spatial locations.

silviculture: the theory and practice of controlling forest establishment, composition, structure, and growth.

standard visual range (SVR): the SVR is the greatest distance at which an observer can barely see a black object viewed against the horizon sky. The higher the SVR value—usually expressed in kilometers—the better the visibility conditions.

sulfur dioxide (SO₂): a colorless gas produced by industrial processes, especially the burning of fossil fuels such as coal and oil. Most sulfur dioxide emissions come from large power plants, refineries, and smelters. This gas is transformed in the atmosphere to sulfate particles and sulfuric acid, which can be transported to surface waters and soils in wetfall or dryfall. SO₂ is the form of sulfur that provides the basis of emission mass calculations for NAAQS.

visibility impairment: the extent to which haze obscures clarity, color, texture, and form.

volatile organic compounds (VOC): numerous carbon compounds that readily vaporize. Many such compounds are precursors in the formation of atmospheric ozone.

Glossary of Abbreviations and Acronyms

AIRS: Aerometric Information Retrieval System (of the U.S. EPA)

Al: aluminum

ANC: acid neutralizing capacity

AQRV's: air-quality related values

B_{ext}: a light-extinction coefficient that represents the ability of the atmosphere to absorb and scatter light

CAA: Clean Air Act

dv: deciview

EPA: U.S. Environmental Protection Agency

FL DEP: Florida Department of Environmental Protection

GIS: Geographic Information System

IMPROVE: Interagency Monitoring of Protected Visual Environments

μg m⁻³: microgram per cubic meter

NAAQS: National Ambient Air Quality Standards

NAPAP: National Acid Precipitation Assessment Program

NO_x: nitrogen oxide

NOAA: National Oceanic and Atmospheric Administration

NRC: National Research Council

NSWS: National Surface Water Survey

OK WRB: Oklahoma Water Resources Board

PEI: Pollution Exposure Index

pH: a measure of hydrogen ion concentration or acidity

PM: particulate matter

PM₁₀: that portion of particulate matter that has an aerodynamic diameter of 10 microns or less

PM_{2.5}: that portion of particulate matter that has an aerodynamic diameter of 2.5 microns or less

ppm: parts per million

SAMAB: Southern Appalachian Man and the Biosphere

SO₂: sodium dioxide

SVR: standard visual range

TSP: total suspended particles

USDA: United States Department of Agriculture

USDA FS: USDA Forest Service

USDI: United States Department of the Interior

U.S. EPA: U.S. Environmental Protection Agency

VOC: volatile organic compounds

W126: a mathematical index of ozone exposure that places emphasis on high concentrations of ozone but does not ignore potential effects that can occur at lower concentrations; a statistically weighted function to describe ozone exposures for a predefined time

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This publication provides information about the atmospheric conditions in and near the national forests in the Ozark-Ouachita Highlands: the Mark Twain in Missouri, the Ouachita in Arkansas and Oklahoma, and the Ozark-St. Francis National Forests in Arkansas. This report includes information about particulate matter, visibility, ozone concentrations, and acid deposition in the Ozark-Ouachita Highlands Assessment area.

Keywords: Acid deposition, Clean Air Act, ozone, particulate matter, pollution, visibility.



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This report is one of five that documents the results of the Ozark-Ouachita Highlands Assessment. Three of the remaining reports examine *Aquatic Conditions*, *Social and Economic Conditions*, and *Terrestrial Vegetation and Wildlife*, respectively, and the fourth provides an overall summary.

